THE MANGROVES OF THE DAMPIER ARCHIPELAGO WESTERN AUSTRALIA

by

V. Semeniuk

and

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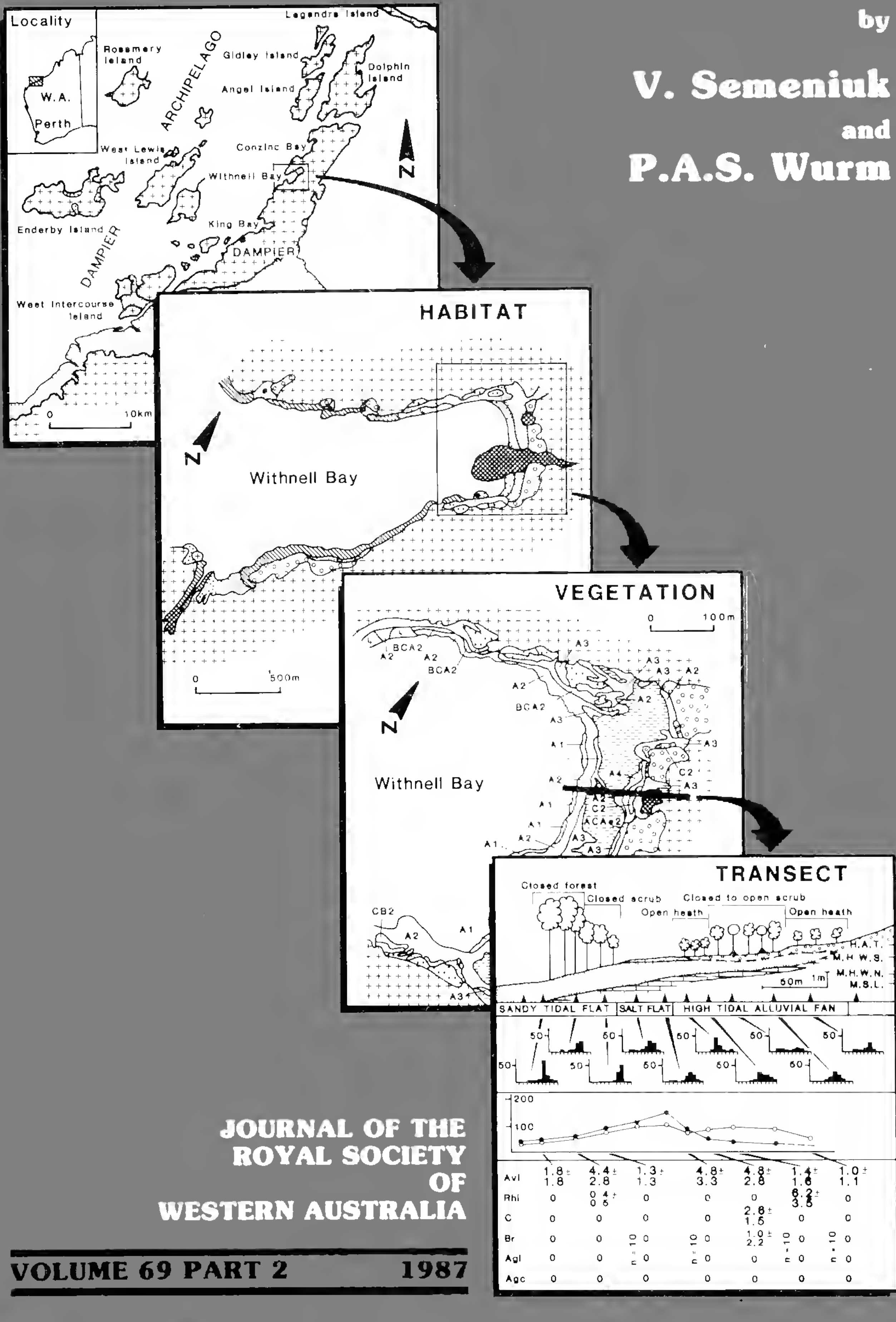

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Mangroves of the Dampier Archipelago, Western Australia

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Abstract

The mangrove habitats, vegetation assemblages and vegetation structural and floristic types along the coast of the Dampier Archipelago occur in definitive and discrete locations that are related to coastal evolution, geomorphology, and a range of physico-chemical and biological factors. The disposition and evolution of coastal environments has been determined by the interaction of the oceanography/meteorology with the ancestral geomorphology of the Precambrian rock hinterland. The large scale coastal geomorphic units which have developed are: straight sandy and rocky coasts; embayments and straits: and connective tidal lands. Medium scale, intertidal geomorphic units developed within the large scale setting include: rocky shores, gravelly, sandy and muddy tidal flats, spits and cheniers, sandy beaches, tidal creeks, shoals, tidal lagoons, mid and high tidal alluvial fans, limestone pavements and the hinterland margin. Habitats for mangroves and an associated mangrove assemblage are developed on these geomorphic units in response to salinity, tidal level and substrate.

Various selected areas in the region are described to provide an indication of the variability of mangrove habitats and vegetation. There is a heterogeneous distribution of habitats in each of the areas at the small and medium scale, with the embayment setting containing the most heterogeneous aggregate of habitats. However, while small scale heterogeneity is emphasised it is also noted that many habitats are recurring. For instance, rocky shores are widespread units and may be considered to be *the* most common habitat in the region. Other units, while discrete in occurrence and limited in area, also are quite widespread when viewed regionally. Mangroves are most luxuriant, abundant, and diverse in embayments and connective tidal-lands. The most species rich, zoned mangal occurs in two main environments: (1) on some alluvial fans and (2) peripheral to sandy terrains, such as spits and beaches.

Six mangrove species occur in the Dampier Archipelago area: *Avicennia marina, Aegialitis annulata, Aegiceras corniculatum, Bruguiera exaristata, Ceriops tagal* and *Rhizophora stylosa*. Environmental forcing factors can only influence three aspects of mangrove populations: their composition, structure and maintenance. Since there is only a small species pool in the region, environmental gradients and differences between habitats therefore are reflected in a variety of structural and physiognomic types within the limited floristic assemblage. Although the vegetation, comprised of structural/floristic units, that occurs on a given habitat may vary locally, generally recurring patterns of distribution can be determined. The muddy tidal flats support scrub of a seaward *Rhizophora* zone and a landward *Avicennia* zone. Sandy tidal flats support a physiognomically-zoned *Avicennia*, grading from forest at its seaward edge, through scrub to heath or low shrubland. Rocky/bouldery shores support a monospecific *Avicennia* shrubland or scrub. Spits and cheniers support zones of *Avicennia* shrubland, *Ceriops* scrub, *Bruguiera* scrub and *Avicennia* scrub. Beaches support an *Avicennia* scrub which may be mixed with *Ceriops, Bruguiera, Aegialitis* and *Aegiceras*. *Avicennia* scrub occurs along the hinterland margin, along high tidal dune margins, and along high tidal lagoons. Tidal creek banks are vegetated by *Rhizophora* and/or *Avicennia* forest or scrub. Small accretionery shoals in tidal creeks support an *Aegiceras* scrub with an understorey of *Aegialitis*. Limestone pavements support an *Avicennia* shrubland. Gravelly tidal flats support an *Avicennia* scrub. High tidal alluvial fans support a mixed *Ceriops* and *Avicennia* shrubland or scrub. Mid-tidal alluvial fans support a physiognomically zoned *Avicennia* scrub with patches of *Rhizophora* scrub.

The approach adopted in this study has tended to emphasise the physico-chemical factors that lead to coastal heterogeneity and habitat variability at various scales of reference. Thus this paper provides a framework within which the distribution and internal heterogeneity of mangrove formations may be understood by resolution of the essential features of habitat evolution, maintenance and distribution. Mangroves then are viewed simply as opportunistic inhabitants that respond to the variable environment by changes in their composition, physiognomy, structure and maintenance strategies.

Introduction

This paper reports on studies conducted over several years on the mangroves of the Dampier Archipelago (Fig. 1). Previous publications have dealt with regional geology (Geological Survey of W.A. 1980), climate (Bureau of Meteorology 1973, 1976), both marine and terrestrial flora and fauna (Wilson and Marsh 1974, Beard 1975, Blaber *et al.* 1985, Storr 1984). The first most comprehensive published works on the natural history of the area dealt with the coastal landforms, habitats and biota, with brief description of the littoral vegetation (Burbidge and Prince 1972; Semeniuk *et al.* 1982).

Mangrove species in mangals (mangal = "mangrove community" after MacNae 1968) of the Dampier Archipelago have been listed by Semeniuk *et al.* (1978) as part of a regional study of Western Australian mangroves. Published data on mangrove environments of Dampier Archipelago also are provided by: Bridgewater (1982) who applied the classification approach of Chapman (1977) to some localities in this region; Semeniuk (1983), in a regional study of freshwater seepage and its effect on mangrove distributions; and by Semeniuk (1985), in a regional study of ria type shorelines and their habitats. These studies do not provide information about the variability and detail of mangrove environments of the Dampier Archipelago to the level presented here.

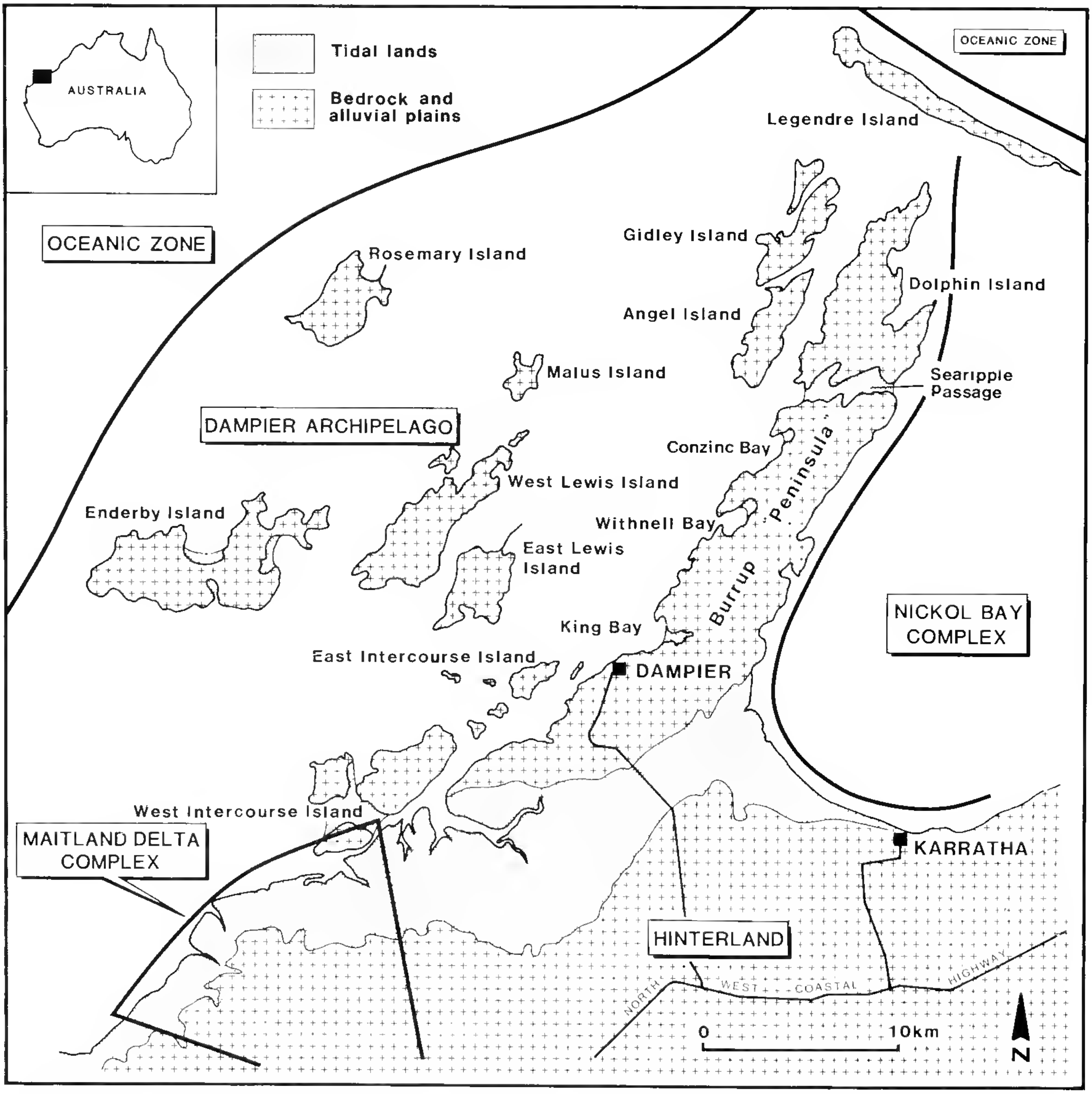

Figure 1.—Locality diagram showing geographic features of the Dampier Archipelago mentioned in this paper, and location of the regional scale geomorphic units.

The objectives of this paper are to provide:

- a description of the Dampier Archipelago mangrove environments in terms of coastal morphology, stratigraphy, substrates and hydrology, all of which are useful in understanding the physico-chemical basis of the mangrove systems;
- a classification of mangrove habitats of the Dampier Archipelago;
- a description of the distribution, structure and composition of mangrove assemblages;
- a description of selected representative mangrove areas of the region.

As a result, this paper provides a philosophy of approach in describing mangrove systems by classifying mangrove habitats as a prerequisite to analysing mangrove assemblages. Other studies elsewhere to date have tended to emphasise the floristic or structural/floristic attributes of mangrove formations but the approach adopted here has emphasised the physical basis of mangrove distribution and mangrove compositional and structural heterogeneity.

Methods

In documenting mangrove environments, it is necessary to use an interdisciplinary approach, utilising data on regional setting and processes with that of the

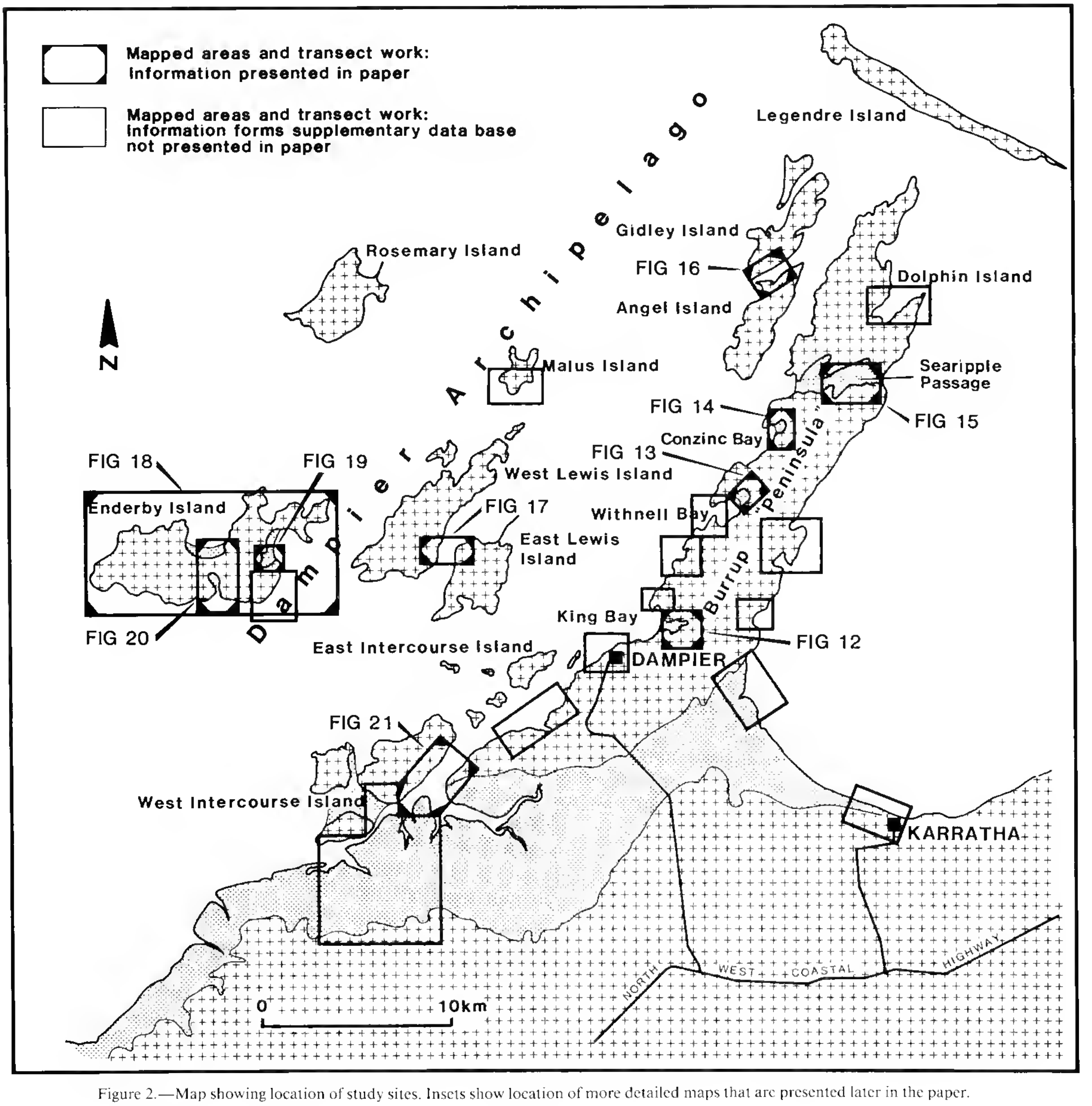

Figure 2.—Map showing location of study sites. Insets show location of more detailed maps that are presented later in the paper.

local environment, and integrating data on physiography, oceanography, hydrology, chemistry, sedimentology, soils, stratigraphy, and biology. Terminology in this paper for the scalar frames of reference and the geomorphic units therein is after Semeniuk (1986). In the documentation of mangrove environments of Dampier Archipelago aerial photographs and field surveys were used to identify the main large-scale coastal types. The various phototones developed by the different substrate types, habitat types and mangroves were then investigated by continuous traverses through the tidal zone and mangal. Spot checks of numerous other sites that had distinctive and/or unusual phototones on aerial photographs also were carried out. The main mangrove and adjoining environments readily identified by phototones and consequently investigated were: (1) mangroves on alluvial fans, (2) mangroves fringing the hinterland, (3) high-tidal mangroves fringing spits/cheniers, (4) stands of *Ceriops*, (5) stands of *Rhizophora*, (6) stands of *Avicennia* (with or without other species), (7) salt flats, (8) terrestrial parts of spits/cheniers, (9) mangroves on rocky shores, and (10) mangroves on mid tidal shoals. Additional geomorphic and vegetation units were identified on site.

At the large scale, the entire coastline of the Dampier Archipelago was surveyed for this study by boat and by helicopter and information from these surveys, together with analyses of aerial photographs, forms the data base for regional distribution of mangrove types. Consequently the maps, cross sections and transect locations shown in the figures, presented later, represent only a selection of the entire data base upon which this paper is based.

At the medium and small scales, some 20 selected areas and 70 transects were investigated in detail to study geomorphology, substrate, stratigraphy, soil/groundwater salinity, fauna and flora (Fig. 2). The selected areas were mapped in terms of habitats, mangrove assemblages and vegetation (structure and floristics). The mapping involved ground traverses and low altitude aerial surveys. Transects were then selected for more detailed study. The type of information obtained from transects is presented in Fig. 3. Mangrove composition, height, canopy structure and distribution were documented. At selected intervals, usually in the middle of a zone or phototone, the composition and density (i.e. number of individuals) of the vegetation was quantified within five replicate 5 m x 5 m quadrats. In many locations ten, fifteen or twenty replicates were used because of low numbers of individuals or variability of composition. In total some 2 000 quadrats were documented.

Fauna were sampled and counted using box cores, or were counted in 5 m x 5 m or 1 m x 1 m quadrats. Cryptic fauna were observed and collected from crevices, logs and mangrove trunks and branches. Conclusions pertaining to the function of fauna in mangrove environments were obtained by observing faunal behaviour and by field experimentation.

Substrate and groundwater/soilwater were sampled at the same localities as vegetation study sites. Soil, excavated up to 100 cm deep, depending on the depth of the water table, was described in terms of colour, structure, fabric, texture and composition. Samples of the surface soil and the groundwater table were collected for salinity analyses. Soil samples were hermetically sealed, frozen, and thawed when ready for laboratory analysis. Groundwater samples, and water extracted from soil samples, were filtered through a 0.045 μm filter and analysed for total dissolved solids by evaporation technique. Soil samples were subsequently sieved at 1 phi intervals for granulometric analyses. The stratigraphy of sites was investigated by pits (0.3-1.2 m deep), auger (up to 3 m deep), by coring, and by probing with an extendable rod to 6 m deep. The following rock/sediment types could be differentiated in the subsurface by probing: (1) mud, (2) sand, (3) muddy sand, (4) interlayed sandy and muddy sediment, (5) gravelly sediment, (6) rock. Terminology for the geometry of stratigraphic units is after Krynine (1948) and Fairbridge (1968).

Description of Dampier Archipelago Environment: Regional Setting

Climate

The Dampier Archipelago coastal environment has a tropical arid climate (BWh of Köppen 1936) with two major seasons: a wet summer season and a dry, warm winter season. Gentilli (1971) considered the area as "pseudo-monsoonal". Bureau of Meteorology (1973, 1975) data show that the area has a mean of some 33 rainy days per year with about 315 mm of precipitation. Mean maximum and minimum temperature in summer in February is 37.1°C and 26.4°C respectively. Mean maximum and mean minimum temperatures in winter in July are 26.3°C, and 14.0°C, respectively. Mean evaporation is 3,518 mm per year with a mean monthly minimum of 193 mm during July, and a mean monthly maximum of 384 mm during December.

Wind originates from various sectors dependent on the time of day and season (Bureau of Meteorology 1973). The area may be considered to have 2 major wind seasons, winter and summer (Steedman 1985). The period between the major seasons is a time of fluctuating winds and general calms. In winter, a high pressure anticyclone belt controls the regional wind pattern with development of easterly through to southerly winds (Gentilli 1971, 1972; Bureau of Meteorology 1973, 1976). In summer strong southwesterly through to northwesterly winds are generated by the interaction of a semi-permanent low pressure trough and the adjoining high pressure systems (Steedman 1985). Landbreeze/seabreeze effects occur throughout the year and interact with the seasonal regional wind pattern. For instance, landbreezes emanating from southeasterly quadrants reinforce the winter regional pattern, but the winter seabreezes moderate the regional wind pattern. In summer, sea breezes reinforce the westerly regional wind pattern and landbreezes moderate the westerly flow. As a result of interactions of regional wind patterns, winter is characterised by wind emanating from easterly, southeasterly to southerly directions, with moderate wind from northwest in the afternoon, whilst summer is characterised by strong northwesterly, westerly and southwesterly wind and moderated wind at night. The wind data, based on 15 yrs record (Bureau of Meteorology 1983), are summarized in Figure 4.

Summer is also the period of local thunderstorms and tropical cyclones which impinge on the coast. Coleman (1971) and Lorensz (1981) show that a cyclone passes within 100 km of this coast about every 10 years, and within 150 km about every 5-10 years. The cyclones are associated with destructive winds, substantial rainfall and storm surges, and are effective agents in mobilising coarse sediments into storm ridges.

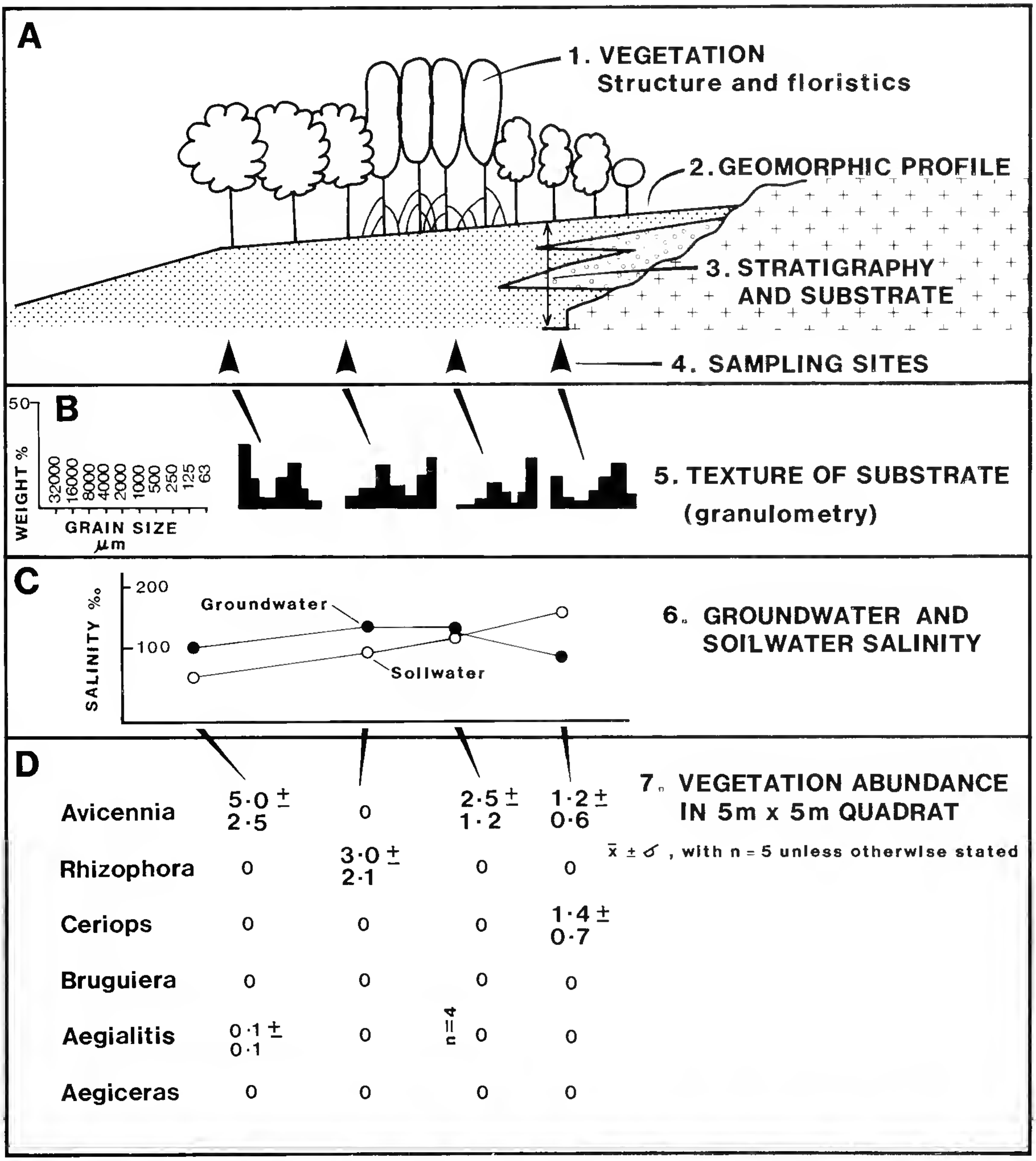

Figure 3.—Schematic profile showing the range of information (numbered 1-7) gathered from field surveys along a transect. This diagram also indicates the style in which data are presented later in Figures 24-30, showing: A, geomorphic, stratigraphic, vegetation structure and floristics results; and location of sampling sites; the vegetation is drawn to scale; B, histograms of grain size distribution of the substrate; C, graph showing salinity of groundwater and soilwater at the various sampling sites across the transect; and D, information on the abundance of mangrove species at each sampling site; abundances are expressed as mean ± standard deviation; the most abundant species at each site are highlighted by bolder and larger typeface. The mangrove names *Avicennia*, *Rhizophora*, *Ceriops*, *Bruguiera*, *Aegialitis* and *Aegiceras* are abbreviated to Avi, Rhi, C, Br, Agl and Agc in the later diagrams.

Oceanography

The tides of the Dampier Archipelago are macrotidal: the maximum range is 6.3 m; the mean spring range is 5.6 m and the mean neap range is 1.0 m (Australian Tide Tables 1985). Long period swell originates in the Southern Indian Ocean and is refracted by the regional bathymetry to approach the Dampier Archipelago mainly from northwesterly and northerly sectors. The swell subsequently is variably refracted and diffracted around the complex bathymetry and islands of the archipelago. Landbreeze/seabreeze systems and thunderstorms generate local short period wind waves which are an important prevailing feature in the coastal zones. Wind waves follow the wind pattern and consequently there is a dominance of locally developed waves from west, northwest and southwest, through to southeast. As a result of the dominant directions of swell and windwaves the portions of coastline exposed to the wave trains have geomorphic features dominated by wave action (e.g. spits, beaches, sand bars, see Figure 4).

Periodically and especially during cyclones there is discharge of freshwater from the adjoining rivers in the region into the marine environment. There is also input of freshwater from the surrounding hinterland by sheet flooding and by the numerous smaller creeks and streams. Subterranean freshwater seepage from the hinterland also continues as an important phenomenon well into the dry seasons (Semeniuk 1983).

Regional Coastal Morphology

Dampier Archipelago is a complex some 1 000 km^2 in area. The Dampier Archipelago region has been divided into five main units by Semeniuk *et al.* (1982). These units are: the Hinterland, Nickol Bay Complex, Maitland Delta Complex, Oceanic Zone and the Dampier Archipelago. Their distribution is shown in Figure 1. The units are described briefly below to provide a context and definition of the Dampier Archipelago unit in its regional setting.

The Hinterland is composed of rocky hills, ridges, colluvial slopes, alluvial flats, river courses, sandplains and subaerial portions of deltas. The bedrock geology of the hinterland consists of folded meta-sedimentary and meta-volcanic rocks and irregularly ovoid domes of granite (Geological Survey of Western Australia 1980). The margin of the hinterland within the Dampier Archipelago may be irregular and diffuse where low-lying supratidal flats, extensive high tidal salt flats, alluvial valleys and deltaic lobes form a broad zone of contact.

The Nickol Bay Complex is a large shallow marine embayment with shoreline tidal flats, dunes, limestone pavements and rocky shores. The contact with the Dampier Archipelago is sharp and located at the eastern margin of the chain of bedrock islands. The Maitland Delta Complex is a coastal lowland comprised of deltaic landforms such as sand ridges, riverine and tidal channels and tidal flats. The contact with the Dampier Archipelago is gradational and placed at the outer limit of the deltaic sand ridges. The Oceanic Zone characterised by deep oceanic environments (greater than 20m depth) has an abrupt contact with the Dampier Archipelago marked by a steep slope.

The Dampier Archipelago is an inundated landmass similar in topography to the present hinterland. The ancient arid zone landforms of the region, consisting of elevated ranges, ridges, hills, hillocks, plains and alluvial fans, have determined to a large extent the configuration and disposition of coastal and marine morphology and environments within the Dampier Archipelago. A gently inclined undulating submerged plain now occurs 5-20m below mean sea level (e.g. Mermaid Sound). Inundated hills and ridges rise up from this plain, the lowest forming subtidal rocky reefs, the highest forming the numerous islands of the archipelago. Inundated valleys form the embayments, straits and channels of the archipelago. Much of the coastline is Precambrian igneous rock. Pleistocene limestone is locally plastered onto this rock. Overlying all rock types is a veneer of varying thickness of sand, gravel or mud. Each of these substrate types occurs in a range of locations which vary according to height above or below mean sea level, topographical configuration and exposure to waves and currents. Consequently, numerous medium to small-scale geomorphic units can be differentiated within the Dampier Archipelago mainly on substrate type, geometry and substrate surface and tidal level. The units have developed by a combination of factors which include: erosion versus sedimentation, underlying stratigraphic sequence, tidal level, wave action and ancestral (pre-Holocene) physiography. The geomorphic units are: (1) Intertidal rocky shore, (2) Subtidal rocky shore, (3) Intertidal limestone pavements, (4) Subtidal limestone pavement, (5) Intertidal flats, (6) Intertidal beaches, (7) Subtidal shoals, and (8) Subtidal plains. A description of these medium scale geomorphic units, their distribution and their occurrence within regional coastal morphology types of the Dampier Archipelago have been presented in Table 2 of Semeniuk *et al.* (1982).

PHYSICAL FRAMEWORK AND HABITATS

Geomorphology

Prior to the post-glacial transgression, the Dampier Archipelago was a dissected terrain which had a subdued drainage, scattered subplanar lowland plains, linear ranges and ridges, scattered hillocks, knolls and hills, and riverine courses. Marine flooding and sedimentary infill of this terrain has resulted in the development of deep water sounds, narrow embayments, broad embayments, islands and connective tidal-lands between these islands (Semeniuk *et al.* 1982). For purposes of describing mangrove habitats the shorelines of this island-dominated system at the *large scale* can be subdivided into the following intergradational units (Fig. 5):

(1) *Straight coasts*, which are composed of *open rocky-boulder shores* or *open sandy beach-dune shores*.

(2) *Embayments and straits*, where valley courses have been flooded by the post-glacial transgression and infilled with sedimentary deposits: these embayments/straits vary from narrow to broad and from small (e.g. Noname Creek) to large (e.g. King Bay). Many of the embayments are exposed to waves at their entrances such that reworking of sediments has developed spits/cheniers.

(3) *Connective tidal-lands*, which develop where hills of the original terrain have been surrounded and isolated by tidal deposits to form islands. Some islands, where exposed to wave action, have bordering spits but mostly they are protected and have muddy *connective tidal-lands* which join with the mainland or other islands. The islands and connective tidal-lands are gradational in size from large-scale features such as the West Intercourse Island system to small hillocks on the tidal flat.

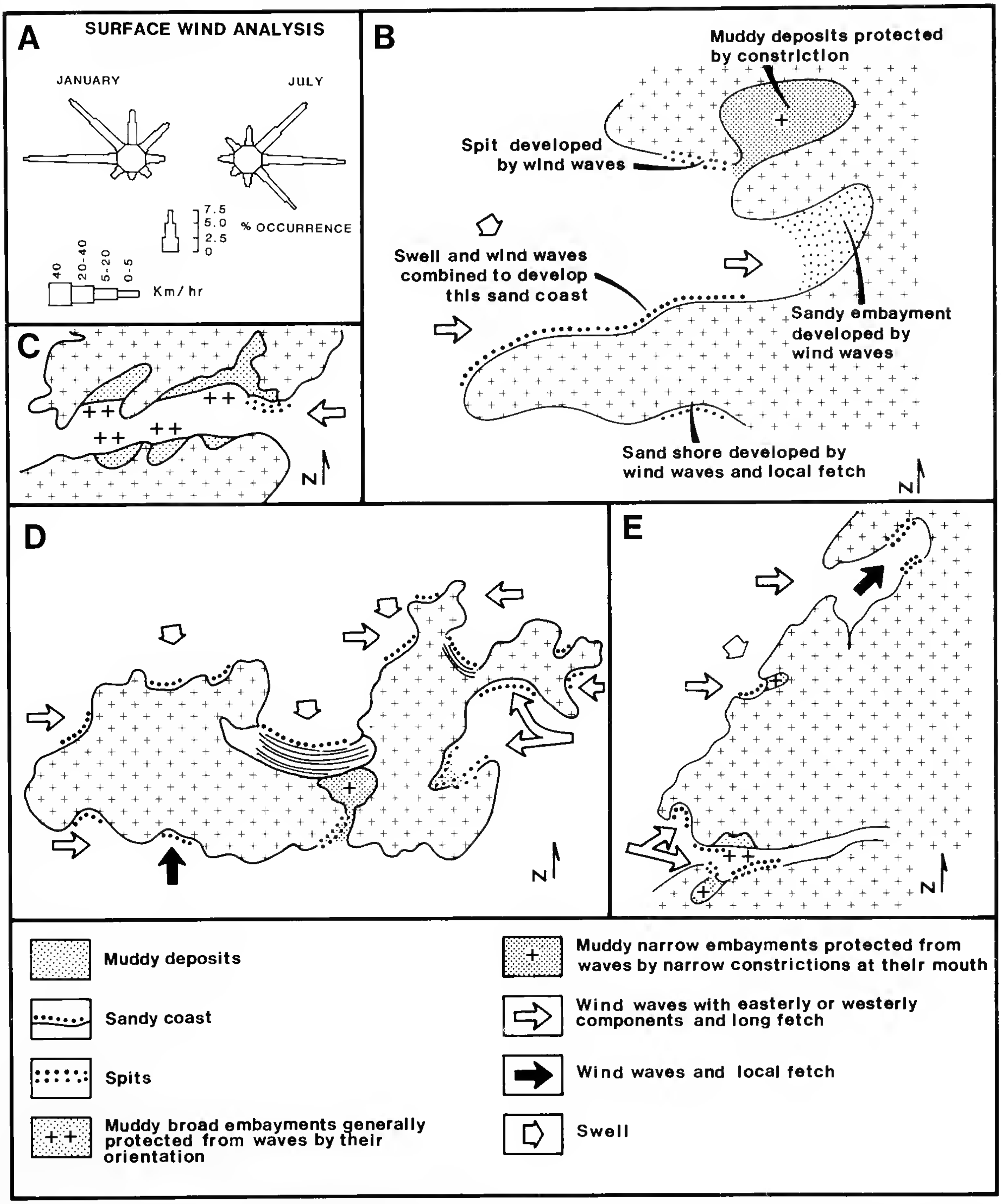

Figure 4.—Relationship of oceanography/meteorology to coastal features. A. Summary of surface wind analysis which incorporates 15 years data from Bureau of Meteorology (1983). B. Schematic diagram showing how various coastal features such as muddy embayments, spits and sandy coasts are developed by oceanographic/meteorologic factors. C. D. and E. The influence of oceanographic/meteorologic factors on the coastline of Searipple Passage (C), Enderby Island (D) and the western shore of Burrup "Island" from King Bay in the south to Conzinc Bay in the north (E).

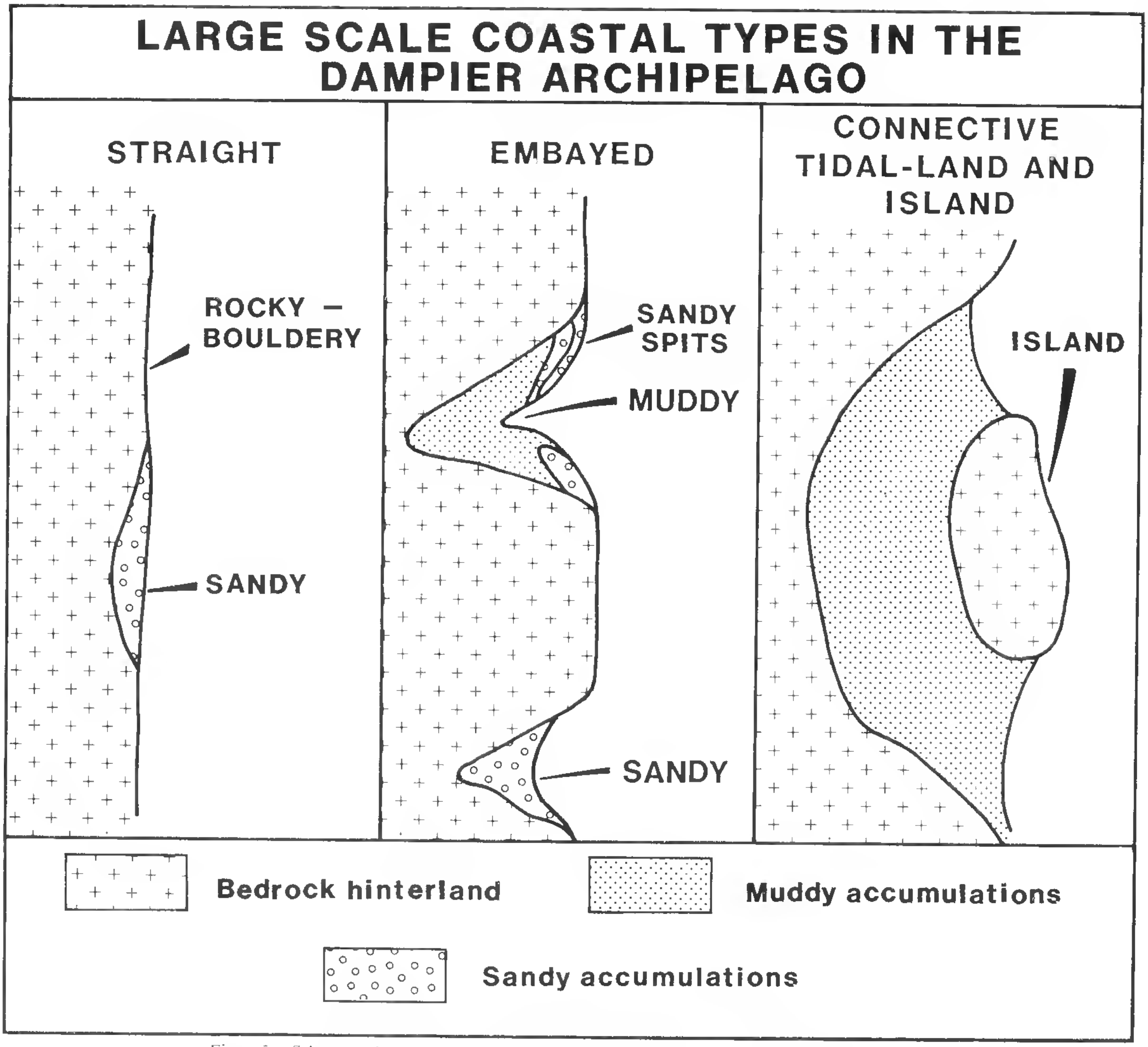

Figure 5.—Schematic diagram showing large scale coastal types in the Dampier Archipelago.

The medium-scale coastal geomorphology of the Dampier Archipelago area has been determined by the smaller-scale geomorphology of the ancestral bedrock topography and by processes of marine sedimentation and erosion. For example, protected embayments have accumulated a mud wedge (tidal flat) which is dissected locally by tidal creeks. Semi-protected embayments have accumulated a sand sheet or mud wedge (tidal flat) with encroaching sand spits formed by wave reworking and tidal dispersion. Exposed straight coasts either have rocky shores winnowed free of major sedimentary accumulations, or have spits which develop muddy accumulations on their protected side, or have sandy beach shores.

Subsequently, depending on the range of interacting physical processes, such as mud and sand sedimentation, tidal creek erosion, wave erosion, or conditions of sedimentary equilibrium, there has developed a wide range of *medium scale* tidal zone geomorphic units (Fig. 6). These units generally are developed either peripheral to the main shorelines along large islands, or circumferential to smaller islands.

A description of the physical features and origin of the medium scale units follows.

(1) *Hinterland margin*: a unit (10-50 m wide) at the junction of the rocky hinterland and the tidal flat that is underlain by reworked colluvium or muddy sand washed off the hinterland; it is inundated only on the highest tide and is subject to freshwater seepage; it should be noted that this unit is distinct from a high tidal dune margin.

(2) *Alluvial fan*: alluvial accumulations, fan to deltoid in shape, that form in mid to high tidal environments where supratidal, terrestrial creeks and streams debouch onto tidal flats; this unit occurs particularly at the mouths of large creeks; substrates are sandy and gravelly and mixed with mud; the fans are subject to freshwater seepage.

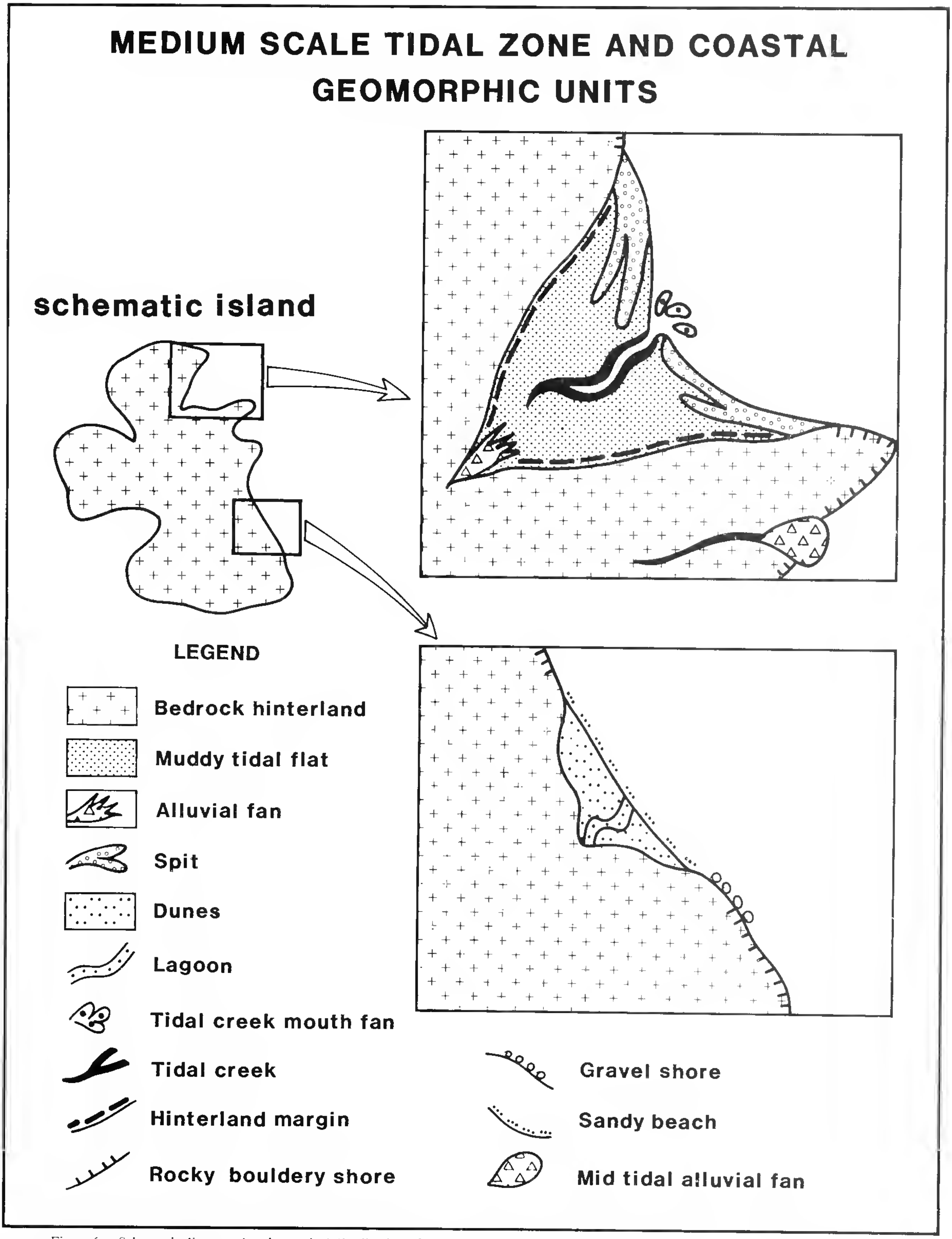

Figure 6.—Schematic diagram showing typical distribution of medium scale geomorphic units within embayment and straight coast settings.

(3) *Tidal flats*: broad (100 m to more than 1 km) gently inclined surfaces underlain by sand in low tidal levels and mud, muddy sand or sand in mid to high tidal levels; generally mud is the more common substrate in mid to high tidal levels but sand is common where tidal flats front a dune system or a spit or chenier system; mid to high tidal flats are vegetated by mangroves; tidal flats have formed where shorelines have markedly accreted in the Holocene; a *salt flat* is developed at high tidal levels where mangroves are absent due to the development of a hypersaline to brine groundwater/soilwater field; locally the mangrove-vegetated tidal flat is truncated at its seaward margin by a small (1-2 m) cliff cut into tidal-flat muds.

(4) *Tidal creeks*: these channels are erosional features (3 m-10 m wide, and approximately 2 m-3 m deep) that meander and bifurcate across tidal flats; small-scale shoals may develop in the creeks.

(5) *Spits/Cheniers*: elongate, narrow (10-50 m wide) sand and shelly sand deposits which are wave-developed features; spits typically emanate from exposed to semi-exposed headlands; cheniers are detached from headlands; although superficially similar, the inter-tidal margin of spits and cheniers is distinct from beaches in its relationship to the tidal gradient e.g. beaches are parallel to shore and spits may transect the tidal gradient.

(6) *Sandy beaches*: narrow, steeply-inclined surfaces of sand and shelly sand fronting exposed coastal situations.

(7) *Lagoons*: high tidal, shallow drainage channels, or creeks, or depressions, up to 50 m wide and 500 m long, barred or impounded by dunes and beach ridges.

(8) *Rocky-bouldery shores*: steeply inclined to cliffed, fissured rocky to bouldery shores comprised of rock boulders or bedrock; these shores generally are wave-exposed environments.

(9) *Gravel shores*: steeply inclined shores comprised of rock gravel sheets; these shores also are generally wave-exposed.

(10) *Shoals*: accumulations of lensoid and linear mounds of sand and shelly sand (100 m or more in width) situated at mid tidal levels; the surfaces are plane to hummocky.

(11) *Small islands*: emergent bedrock prominences several metres to tens of metres across usually surrounded by tidal deposits.

(12) *Dunes*: supratidal sand ribbons to mounds 10 m to greater than 1 000 m wide accumulated as onshore aeolian deposits.

(13) *Subtidal channels and bays*: permanently-inundated environments that adjoin the tidal zone units listed above; the units are underlain by rock, sand or mud depending upon which tidal zone unit is adjoining; these units are not discussed further in this paper.

All the units except dunes, subtidal channels and bays are important as mangrove habitats and may support littoral vegetation in their mid tidal to upper tidal range. It should also be noted that this number of geomorphic units expands the list presented by Semeniuk (1985) for ria components in the Dampier Archipelago region. The distribution and relative abundance of these medium-scale units in relationship to the large-scale geomorphology is summarised in Table 1. The disposition of the medium-scale geomorphic units also is shown for selected small areas in the maps presented later in the text.

TABLE 1

Distribution and Relative Abundance of Medium Scale Geomorphic Units Within Large Scale Geomorphic Setting

Large Scale Geomorphic Setting	MEDIUM SCALE GEOMORPHIC UNITS											
	Hinterland Margin	Alluvial Fan	Tidal Flat	Tidal Creek	Spit/ Chenier	Sandy Beach	Lagoon	Rocky-Boulder Shore	Gravel Shore	Shoals	Small Islands	Dunes
Straight coast: rocky/bouldery	—	p	—	—	—	—	—	c	c	—	p	—
Straight coast: sandy	—	u	u	—	u	c	p	—	p	—	p	c
Embayment	c	c	c	p	c	c	p	c	p	p	p	p
Connective tidal land	p	p	c	c	c	p	—	—	p	p	p	—

c common occurrence
p may be present
u uncommon occurrence
— absent

Substrates

Substrates are important in the development of distinct mangrove habitats because grain size and sediment type can directly or indirectly influence various aspects of hydrology and soil fertility. For instance, substrate type can influence internal drainage and accordingly affect various stages of water logging and salinity regimes, and the composition of substrates affects the nutrient uptake, retention or storage properties of a soil.

There are a wide range of substrate types in the tidal zone of the Dampier Archipelago area. However, all can be related to geomorphology and oceanographic aspect and associated processes such as wave action, tidal action, sedimentation, erosion, etc. In the Dampier Archipelago area there are seven major settings for substrates and each has generated distinctive suites of substrates. The settings are listed below in order of decreasing wave exposure.

(1) exposed rocky, bouldery and gravelly shores
(2) exposed sandy shores
(3) semi-protected embayments with spits/cheniers
(4) sheltered sand shores
(5) sheltered muddy shores
(6) terrestrial/tidal flat junction
(7) alluvial fan environments

TABLE 2

Description of Substrates in the Mangrove Environments of the Dampier Archipelago

Substrate Type	Description			Occurrence
	Structure	Fabric, Texture and Composition	Colour	
Bioturbated and root-structured *mud*	bioturbated and root structured	mudstone fabric of mud sized clay minerals, silica carbonates and organic matter	grey to brown	muddy tidal flat
Bioturbated and root-structured *sandy mud*	bioturbated and root structured	wackestone fabric; quartz shell and lithoclast sand in mud matrix	grey to brown	muddy tidal flat
Homogeneous *mud*	homogeneous	mudstone fabric of mud sized clay minerals, silica carbonates and organic matter	grey to brown	muddy tidal flat
Textured-mottled *mud* and *sand*	mottled	mud with patches of sand and sandy mud, or sand with patches of mud	colour variegated: brown, buff and grey	sandy tidal flat; spit margins; chenier margins; dune margins
Homogeneous *muddy sand*	homogeneous	quartz, shell, lithoclast sand with interstitial mud	brown to grey	sandy tidal flat; spit margins; chenier margins; dune margins
Root-structured *muddy sand*	root structured	quartz, shell, lithoclast sand with interstitial mud	brown to grey	sandy tidal flat; spit margins; chenier margins; dune margins
Homogeneous *sand*	homogeneous	grain-supported sand of quartz, shell and lithoclast	buff to brown	sandy tidal flat; spit margins; chenier margins; shoals
Laminated *sand*	texturally layered	grain-supported sand of quartz, shell and lithoclast	buff to brown	dunes; dune margins; beaches; spit margins; chenier margins
Rock *gravel*	structureless	framework of gravel; interstitial sand or mud may be present	interstitial sediment is grey	rocky shores; tidal gravel flats; alluvial fans; hinterland margin
Boulder deposits	structureless to imbricated	framework of boulders; interstitial sand or mud may be present	interstitial sediment is grey	rocky shores; hinterland margins
Interlayered *mud* and *sand*	texturally layered	sand of quartz shell and lithoclast, alternating on a centimetre scale with mud layers	brown to buff	spit margins; chenier margins; shoals
Limestone pavements	—	indurated calcarenite	—	limestone headlands/ pavements
Bedrock pavements and slopes	—	fissured to smooth igneous rock substrates	—	rocky shores

Within each of these settings there are a range of physical processes that influence the development of sediment bodies. The processes significant for the generation of the suites of substrates are: (1) sediment supply, which determines sediment type as well as whether the shores are rocky or covered with sediment; (2) wave and tidal energy, which determine whether the shores are winnowed free of sediment or are covered by winnowed coarser sediments; (3) wave exposure, storm action, and frequency of flooding, which determine within sediment-filled embayments whether the shores are underlain by sand in low tidal zones or by mud in progressively higher tidal zones, and (4) fluviatile input, which determines the amount of coarse sediment (sand and gravel) that is discharged along the hinterland edge and high tidal alluvial fans.

The main components of substrates are mud, sand, shell and rock gravel, limestone and igneous bedrock. Mud is comprised of clay minerals, quartz silt and skeletal silt. Sand is comprised of quartz, rock fragments, or comminuted shell. The gravel component is comprised of shell, the accumulated tests of the marine benthos, and rock gravel which either is eroded hinterland rocks or marine-reworked colluvium. The limestone is Pleistocene calcarenite or Holocene beachrock. Meta-igneous rock that crops out on the hinterland occurs as bedrock. The components of mud, sand and shell and rock gravel when accumulated and mixed develop a wide variety of substrate types. The effect of burrowing biota such as crabs further mixes the sediments and produces homogeneous and bioturbated or burrow-structured substrates. Vegetation contributes to the development of substrate variability by input of detritus and by root structuring.

The main substrates encountered in this study include:

(1) bioturbated and root-structured *mud*
(2) bioturbated and root-structured *sandy mud*
(3) homogeneous *mud*
(4) textured-mottled *mud* and *sand*
(5) homogeneous *muddy sand*
(6) root-structured *muddy sand*
(7) homogeneous *sand*
(8) laminated *sand*
(9) rock *gravel*
(10) *boulder* deposits
(11) interlayered *mud* and *sand*
(12) limestone pavements
(13) bedrock pavements and slopes.

In embayment settings the muddy and sandy substrates are dominant. In straight coastal exposed rock shore settings the gravelly and bouldery substrates are dominant. A summary description of substrate types occurring in each setting is presented in Table 2. The occurrance of these substrate types and their granulometric analyses are noted as surface soils on most profiles presented later in this paper. These units are also encountered in the stratigraphic profiles.

Stratigraphy

The Quaternary stratigraphy of coastal areas such as the Dampier Archipelago is important for at least two reasons. Firstly, it provides an historical context for the origin and distribution of substrates and consequently habitats. Thus it provides information on the longevity and maintenance of mangrove-vegetated habitats since the sedimentary (biotic) lithotopes can form distinctive stratigraphic units. Secondly, the stratigraphy forms the basic framework for the tidal flat hydrology and the tidal flat/hinterland hydrologic exchanges. Since groundwater salinity, recharge and mixing are important physico-chemical elements of mangrove ecosystems, it follows that the stratigraphic array of aquifers and aquatards is an important component of these systems.

Stratigraphic units are differentiated on the basis of geometry, lithology and internal features such as structure and colour. The stratigraphic profile under the tidal zones contains the following units:

(1) *mud and muddy sand wedge:* a thick wedge of bioturbated and root-structured mud which may grade into sandy mud and muddy sand (some formed under mangrove cover). It is at least 2-3 m thick at its seaward edge and pinches out to landward. This deposit occupies the major portion of an embayment. The wedge interdigitates with gravel/sand deposits developed along the hinterland edge, and with sand deposits of the spits/cheniers;
(2) *sand/shelly sand wedge:* a thick wedge of bioturbated to layered sand, shelly sand and muddy sand. It is at least 2-3 m thick at its seaward edge and onlaps older stratigraphic units to landward. The unit occupies a major portion of exposed embayments. The wedge interdigitates with landward gravel/sand deposits and with dune deposits;
(3) *sand sheet:* a thin sheet of sand 10-30 cm thick that forms a blanket on the salt flats. Contact with underlying unit, the mud wedge, is sharp, and it can interdigitate with adjacent sand bars;
(4) *muddy sand/gravel sheet or ribbon:* a sheet or ribbon (*c.* 1 m thick) of muddy sand or gravel sandwiched between the main tidal flat wedge and the hinterland; this deposit is reworked buried soil or colluvium mixed with tidal mud, and has developed where the tidal flat sediments onlapped the hinterland;
(5) *gravel/boulder ribbon:* a narrow and thin accumulation of gravel and boulders developed along rocky shores. The unit is locally muddy/sandy and it is 10-50 cm thick;
(6) *sand/gravel fan:* a fan-shaped (to deltoid-wedge) deposit of sand, muddy sand or gravel, up to 2-3 m thick and tens of metres across, formed where terrestrial drainage has discharged sediment onto the high tidal flats; the alluvial fan interdigitates with the muddy tidal flat wedge;
(7) *gravel fan:* a thick fan-shaped lens, up to several metres thick and greater than 100 m across, formed where major streams have discharged coarse gravelly sediment onto the tidal flats.
(8) *sand bar:* a shoe-string or ribbon-shaped sand or shelly sand unit, up to 100 m wide, 1 000 m long and 3-4 m thick, formed as a (mid-) high-tidal to supratidal spit or chenier. The unit interdigitates with, and progrades over mud wedges; these deposits commonly are located at headland entrances to embayments or along wave-exposed portions of islands.
(9) *dune/beachridge:* a ribbon to prism of fine and medium sand formed as a low coastal aeolian deposit.

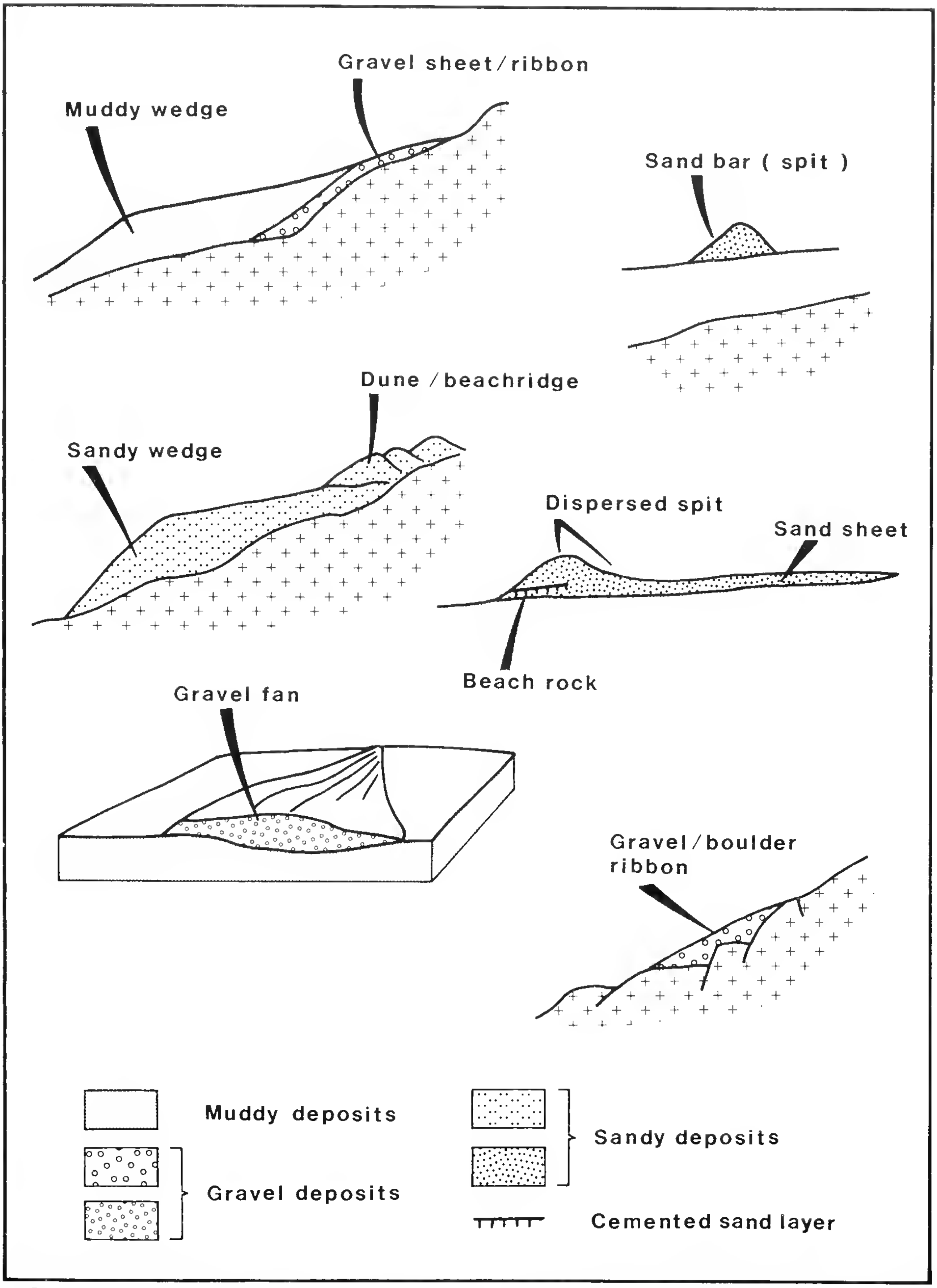

Figure 7.—Schemtic diagram of geometry and disposition of the main stratigraphic units. Actual examples of these units are shown on the transect cross sections presented later in this paper.

(10) *beachrock:* locally cemented sheets and lenses of sand and shelly sand which through erosion has formed low cliffs and high tidal pavements.

(11) *limestone:* a sheet of Pleistocene calcarenite or shelly calcarenite which forms a pavement or ramp in the tidal zone.

(12) *bedrock:* the underlying Precambrian metavolcanic and igneous rock.

The geometric and spatial relationships between stratigraphic units are illustrated schematically in Figure 7.

Specifically, the main tidal flat unit, which is best developed in embayments and in settings of intertidal land connections consists of a wedge of muddy sediment tapering landward and overlying igneous bedrock. This unit may be overlain by or mixed with sand where for example, a sand spit developed on top of the mud wedge has been subsequently geomorphically degraded to form a sand sheet. The contact between the narrow, landward edge of the muddy wedge and the gravelly soils of the hinterland is also represented in the stratigraphy as a muddy gravel sheet. Gravelly and coarse sand units penetrate the mud wedge where terrigenous alluvial deposition occurs (or has occurred) at the margin of the tidal zone. On sandy shores the main tidal wedge is sandy. On the more exposed coast the intertidal unit becomes a discontinuous ribbon of sediment forming patchy veneers, or occurring interstitial to boulders.

Statigraphic profiles show that much of the tidal lands are infilled terrestrial lowlands. The stratigraphy records a gradual infilling during the Holocene by one or more of the lithologic/stratigraphic units described above. On the main tidal flat the sedimentary accumulation has resulted in a wedge of muddy sediment while on exposed sandy coasts the entire stratigraphic interval is composed of sand overlying bedrock. The consistent internal lithology and structure of muddy tidal flat coasts and spit-lined coasts show that these shore types are long-term stable features which, during the latter Holocene, do not appear to alternate between environmental extremes. For instance, on the spit-lined headlands the stratigraphic sections frequently show that a sandy (or muddy sand) spit has interdigitated with tidal flat muds as the shoreline accreted (eg. Figure. 25b). On the other hand some spit sections indicate that they are only recent incursions of a sand bar into a muddy tidal flat environment (Figure. 26C). Alluvial and colluvial discharge onto tidal zones from fluviatile and hinterland sources continue to accrete sediment and thus maintain the geomorphic units/habitats associated with them (Figure 26A).

Groundwater/Soilwater

The occurrence, depth and salinity of the groundwater and soilwater systems on tidal flats and adjoining hinterland are important hydrologic factors that can regulate mangrove populations (MacNae 1968, Chapman 1976, Cintrón *et al.* 1978, Semeniuk 1983, 1985). Indeed zonation of mangrove species documented by numerous authors can be related to groundwater and soilwater hydrology. Soilwater and groundwater can be classified on occurrence and salinity, and the salinity of the various groundwater/soilwater units can be shown to be closely linked to stratigraphy, subtrate, recharge mechanisms and evapo-transpiration. There are six main bodies of groundwater (Semeniuk, 1985 and in prep.). These are:

(1) hinterland and dune groundwater (freshwater)

(2) hinterland and dune margin groundwater (saline/mixed)

(3) alluvial fan groundwater (saline/mixed)

(4) tidal flat groundwater (saline)

(5) spit/chenier groundwater (saline/mixed)

(6) rocky shore groundwater (saline)

Each of these groundwater and soilwater units has its own range of salinity as well as its own internal gradients of salinity and chemical composition. The prevailing mechanisms that result in the variable groundwater and soilwater units are: (1) seawater recharge, (2) freshwater recharge, (3) mixing and (4) evaporation. Ultimately there are only two main sources of groundwater: freshwater (discharged from the hinterland), and marine water (recharged daily, fortnightly, varying to half-yearly). The disposition of aquifers, aquatards and aquicludes within the stratigraphic system, and the processes of marine recharge, groundwater migration, groundwater discharge, evaporation and transpiration interact to produce a gradient of increasing hypersalinity across tidal flats. This gradient is complicated by a zone of mixing between tidal flat groundwater (hypersaline) and freshwater seepage. Examples of this occur along the hinterland margin or alluvial fans. There is also mixing between seawater (seeping from spits and cheniers) and tidal flat groundwater.

The resulting groundwater bodies underlying the tidal zone units have various salinities as shown in Table 3. Soilwater frequently parallels the salinity gradients of groundwater because there is vertical mixing due to recharge by tidal waters and to bioturbation by fauna. However soilwater salinity may differ from that of groundwater because of evaporation effects. A summary of aspects of groundwater and soilwater salinity is presented in Table 3 and Figure 8.

The variability of salinity of groundwater and soilwater along a selected transect is illustrated in Figure 9. This indicates that the variability in salinity at any site is not large and that single samples of groundwater and soilwater are representative of gradient trends.

Hinterland and dune groundwater—The groundwater under the hinterland and dunes is fresh to brackish. It seeps to seaward at the hinterland margin at soil, colluvium and rock interfaces and discharges onto the tidal flats in the subsurface. Where it infiltrates the tidal flat it mixes with, and dilutes tidal groundwater hypersalinity. The hinterland groundwater is recharged seasonally by meteoric water.

Hinterland margin and dune margin groundwater/soilwater—This groundwater and soilwater system resides in a sheet of muddy colluvial soil or in the ribbon of muddy sand, and forms a zone of mixture between tidal flat hypersaline groundwater and freshwater seepage from the hinterland or dunes. As a result there is a gradient from saline water (*c.* 60‰) at landward margins to very hypersaline (90‰) where the system adjoins the main tidal flat. Recharge by seawater is infrequent (varying from monthly to twice-yearly); recharge by freshwater runoff and seepage is perennial, being marked in the wet season and less pronounced in the dry season (Semeniuk 1983). The water table is elevated relative to the adjoining high tidal flat system.

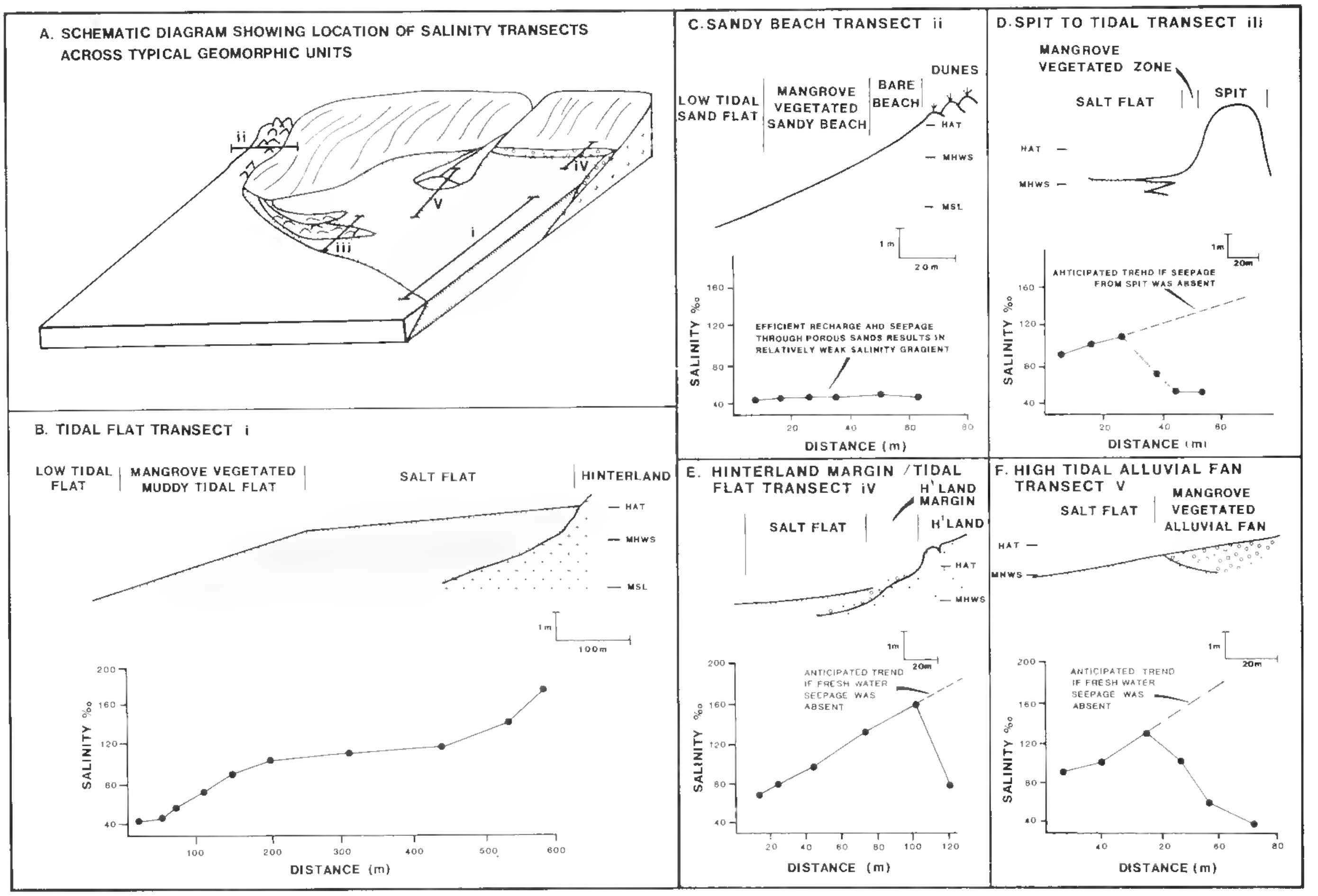

Figure 8.—Relationship of groundwater salinity gradients to transects across various geomorphic units (i-v). A. Schematic diagram showing location of the transects (i-v) in relationship to the geomorphic units. B. C. D, E and F. are examples of the salinity gradients along transect i, ii, iii, iv and v respectively. Each transect is based on an actual field example.

Alluvial fan groundwater/soilwater—The water table of the alluvial fans is elevated by freshwater discharge particularly during the wet season where there is combined surface runoff and subsurface seepage. During the dry season there is ongoing subsurface seepage and the water table is still elevated (0.5 m-1.0 m below the ground) relative to the adjoining high tidal flat. The salinity of groundwater and soilwater of alluvial fans is saline, being *c.* 45-60‰ at landward parts of the system and grades via mixing with hypersaline water up to values of 90‰ where the alluvial fans adjoin the main tidal flat.

Tidal flat groundwater/soilwater—On the main tidal flat groundwater generally occurs about 10 cm below the surface at seaward mangrove locations during low tide periods. Depending on substrate and tides (neap *vs* spring), it is found progressively deeper until it may be greater than 1 m deep under salt flats. Groundwater salinity is *c.* 40‰ at seaward locations where it is recharged daily, and progressively increases up to highly hypersaline values greater than 200‰ above MHWS where it is recharged fortnightly. Groundwater salinity values decrease at the freshwater-influenced zone along the hinterland margin and along the contact with alluvial fans. Soilwater salinity shows a graded increase in salinity from *c.* 40‰ to 300‰ across the tidal flat, with a decrease in values along the freshwater-influenced hinterland edge and alluvial fans.

Spit and chenier groundwater/soilwater—The spit and chenier ground-water resides within the sand bar stratigraphic unit. The sand is well drained and the water table lies generally more than 0.5 m below the surface. The groundwater salinity approximates seawater where there is daily recharge at seaward parts of the spits and chenier. Salinity generally grades up to values of 60-70‰ at levels of HWS where recharge is fortnightly. On the wider emergent terrestrial spits and cheniers there may be a thin lens of freshwater. Soilwater salinity gradients generally follow that of groundwater.

Rocky shore groundwater/soilwater—Groundwater in the rocky shore environments resides in the fissures of rocky substrates or in the interstitial cavities of boulders, slabs and gravel deposits that occur along such shores. Generally, rocky shore environments are well drained and where observed the water table is more than 0.5 m below the surface. The groundwater salinity approximates seawater at levels of MSL and grades up to *c.* 100‰ at levels of MHWS. Soilwater occurring as a pellicular film on rock surfaces and boulders is generally too difficult to sample, but soilwater collected from sediment interstitial to the frame of fissured rock or boulders shows a gradient of salinity similar to groundwater.

TABLE 3

Groundwater/Soilwater Description: Main Aquifers: Properties and TDS of Groundwater: Properties of Soilwater

Aquifer	Groundwater			Soilwater	
	Type of Water	Salinity of Water	Recharge Mechanism	Waterlogging of Soil	Soil Salinity
Hinterland and dune	freshwater to brackish	freshwater to brackish	rainfall	not described since soil does not support mangroves	not described since soil does not support mangroves
Hinterland and dune margin sheet/ribbon	contains water developed by mixing of hypersaline seawater and freshwater seepage from hinterland and freshwater/seawater seepage from dunes	up to 280‰ where there is no freshwater seepage; otherwise with freshwater or seawater seepage 50-90‰	recharged infrequently with seawater by highest tides; recharged perennially or annually by freshwater seepage which precludes any potential extreme hypersalinity	waterlogged during wet season and after (infrequent) tidal flooding	>300‰ but depending on freshwater seepage there may be a gradient of 50‰ up to 90‰
Alluvial fan	contains water developed by mixing of hypersaline seawater and freshwater seepage from hinterland	45-60‰ up to 90‰ dependent on amount of freshwater seepage	recharged infrequently with seawater by highest tides; recharged perennially or annually by freshwater seepage which precludes any potential extreme hypersalinity	waterlogged during wet season, otherwise saturated in phreatic zone (usually 50cm deep)	40‰ to 90‰
Tidal flat wedge	contains water approximating to seawater at seaward portion, grades up to very hypersaline at landward portion	gradient: 40‰ at MSL, 45‰ in mid *Rhizophora* zone, = 90/100‰ at landward edge of mangal grading up to 280‰ across salt flats	recharged daily to fortnightly at levels up to MHWN and MHWS respectively; evapotranspiration and evaporation combine to develop a gradient of increasing hypersalinity	waterlogged most of the time	gradient MSL = 40‰ up to > 300‰ at HAT
Spits/cheniers	contains water approximating normal seawater grading up to hypersaline seawater	40‰ varying to 60-70‰ depending on seawater and freshwater seepage	depending on tidal level, recharged daily to fortnightly by seawater and seasonally by meteoric water	waterlogged during high tide; well-drained during ebb tide	gradient of = 40‰ to 70‰
Rocky shores	contains water approximating normal seawater grading up to hypersaline seawater	= 35‰ at MSL to 90-100‰ at MHWS	depending on tidal level, recharged daily to fortnightly by seawater	waterlogged during high tide; well-drained during ebb tide	gradient of = 30‰ at MSL to 90-100‰ at MHWS, and > 200‰ at HAT

Benthic fauna

The benthic fauna of mangroves are important elements of the ecosystem. The animals function in several ways to facilitate the physico-chemical exchanges and biological processes that are useful and essential to maintaining mangrove populations. The following information on function of the mangrove fauna is based on observations in the Dampier Archipelago mangrove environments and on literature (MacNae 1968; Saenger *et al.* 1977; Milward 1982; Hutchings and Recher 1982).

The benthic fauna have a major function in bioturbation whereby soils are turned over rapidly relative to the life span of a mangrove tree. The bioturbation activities of fauna also aids in the recycling and mixing of sediment, such that groundwater-saturated soils are periodically brought to the surface to provide salinity exchange. In the same way both the mixing of soil by fauna and the burrow conduits themselves facilitate oxygen transfer.

Benthic fauna such as crabs prey upon seedlings and therefore have a major impact on population regulation. Grazing fauna digest fresh and decaying mangrove leaves, leaf detritus and microbial products of mangrove decay, thus assisting either in the fixing or export of nutrient. Fauna such as insects and boring "shipworm", such as *Teredo* sp. contribute to mangrove destruction and thus are a component of the processes of regulation and elimination. Faeces of fauna furthermore provide organically bound mineral particles that are components of the nutrient breakdown and storage cycle. For these reasons, both burrowing and vagile benthic fauna are considered here to be important components of mangrove ecosystems. Information on types of fauna, their relative abundance, distribution and function is presented, according to habitat, in Table 4.

The most diverse and abundant benthic fauna in mangrove environments occurs on muddy tidal flats where the fauna also is well zoned across the flat. The most important components of the fauna are the

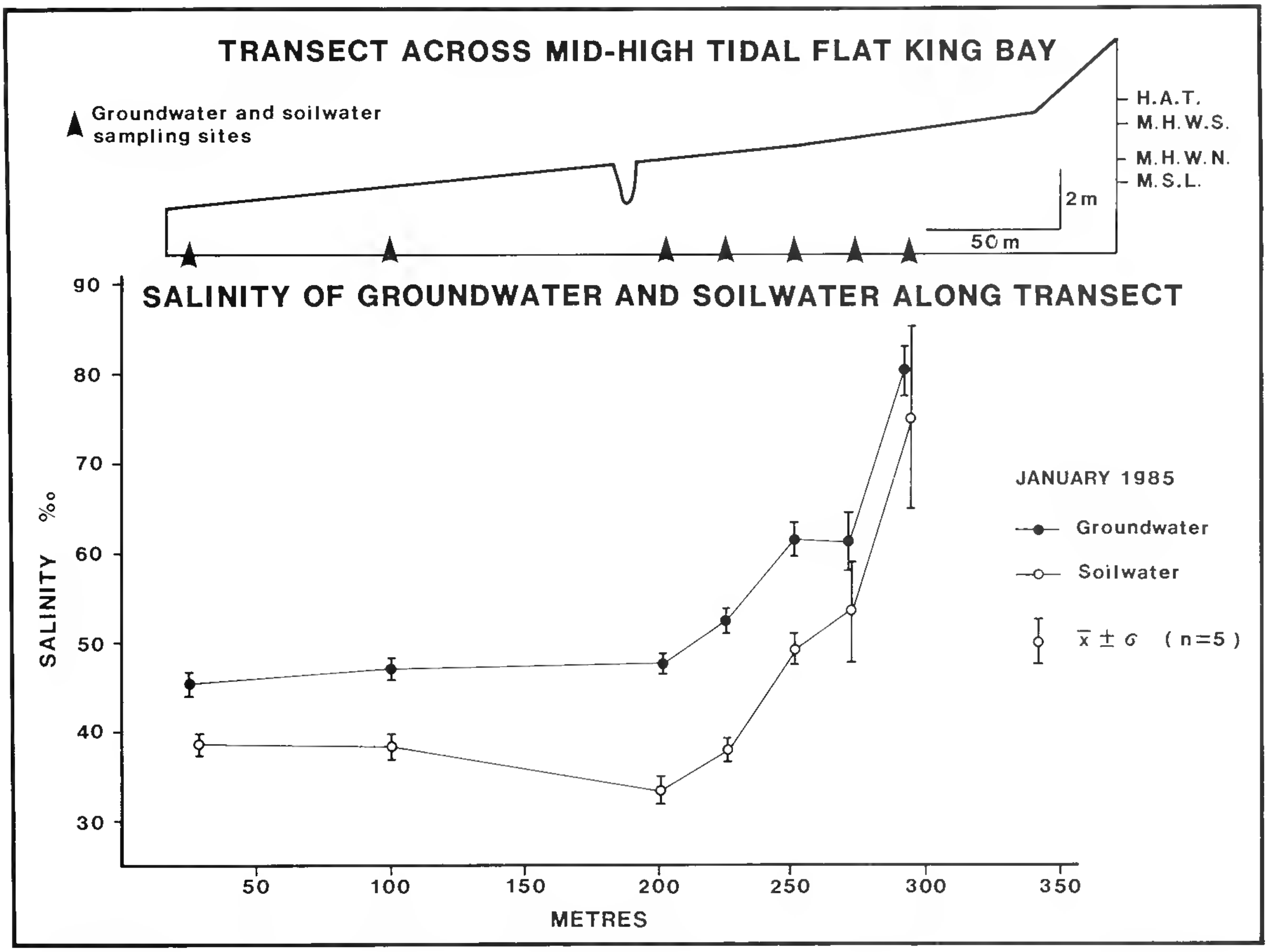

Figure 9.—Transect showing variation in salinity of groundwater and soilwater across tidal flat in King Bay during one sampling survey. This transect is transect 3 of Semeniuk 1983.

burrowing crustaceans (*Thalassina anomala*, *Sesarma* spp, *Uca* spp), peanut worms *Phascolosoma*, burrowing fish, together with grazing molluscs and predatory *Sesarma*. In the other mangrove habitats fauna is less abundant. In the gravelly environments of alluvial fans, hinterland margins and rocky shores the fauna resides in sediment interstitial to a gravel/boulder frame. Sandy beaches, sandy tidal flats, spits and dune margins support the least abundant and least diverse fauna. However, in zones which are transitional between sand and mud, burrowing crustaceans (e.g. *Thalassina* and *Metopograpsus*) are important in bioturbation and in developing water exchange conduits.

Classification of Mangrove Habitats in the Dampier Archipelago

Approach to classification

The identification of mangrove habitats rests on the fact that mangroves inhabit geomorphic units that have distinct morphology, substrate, salinity, etc. Adjoining areas, not vegetated by mangroves, of course, can be mapped to define the boundary and extent of a given mangrove formation. Once the occurrence of a mangrove formation is defined, the recognition of habitat types is achieved by identifying the physical and chemical features (such as spits and alluvial fans, etc.) within the system. Thus within an embayment with extensive well developed mangroves, for instance, there may be distinguished alluvial fans, spits, tidal creeks, etc., each with their influence on mangrove occurrence, abundance, composition and physiognomy. By not resolving and identifying the geomorphic units (or habitats) within the embayment, the heterogeneity evident in the mangrove formations tends to be viewed as mosaics of differing floristics and structure. The habitat approach adopted here (following Semeniuk 1985) attempts to reconcile, at the large and medium scales of reference, some of the variation in mangrove formations with the more obvious physico-chemical features in the environment.

The mangrove habitats of the Dampier Archipelago

The important factors in development of mangrove habitats are tidal level, substrate type, stratigraphy and salinity. These are inter-related and their interaction develops distinct habitats for mangroves in this area. Substrates are developed within a given geomorphic unit and are related to tidal and wave processes at a specific tidal level on the shore. The tidal level and substrate in turn influence recharge rate and evaporation, and hence salinity of groundwater and soilwater. Specific medium

TABLE 4

Occurrence, Abundance and Function of Benthic Fauna in Mangrove Environments of the Dampier Archipelago

Habitat	Main Fauna			
	Types[1]		Abundance[2]	Function[3]
Muddy tidal flat	Crustacea:	*Sesarma* spp.	medium	A C D E G
		Thalassina anomala	low/medium	A B C D
		Uca spp	medium	A C D
		Scylla serrata	low	A C D
		Epixanthus dentatus	low	A C D
		Metopograpsus frontalis	low	A C D E G
		Alpheus sp	low	A C D
	Siphunculid:	*Phascolosoma*	high	A C D
	Mollusca:	Teredinids	high	F
		Telescopium telescopium	low/medium	I
		Nerita lineata	low/medium	I
		Onchidium	low/medium	I
	Pisces:	gobioid fish	low/medium	A C D
Sandy tidal flat	Crustacea:	*Sesarma* spp	low	A C D E G
		Uca sp	low	A C D
	Mollusca:	Teredinids	high	F
		Terebralia sulcata	medium/high	I
		Terebralia palustris	medium/high	I
	Pisces:	gobioid fish	low	A C D
Rocky bouldery shore	Crustacea:	*Metopograpsus frontalis*	low	G
		Sesarma spp	low	A C D G
		Petrolithes teres	low	?
	Mollusca:	*Nerita* spp	low	I
		various gastropods	low	H I
Spits/cheniers	Crustacea:	*Ocypode* spp	low	A C D
		Metopograpsus frontalis	low	A C D G
	Mollusca:	Teredinids	high	F
		Terebralia sulcata	low	I
		Terebralia palustris	low	I
Beach	Crustacea:	*Ocypode* spp	low	A C D
		Scopimera sp	medium/low	A C D
		Mictyris sp	medium/low	A C D
Hinterland margin	Crustacea:	*Sesarma* sp	low/medium	A C D E G
		Uca sp	low	A C D
Gravel tidal flat	Crustacea:	*Sesarma* spp	low	A C D E G
		Petrolithes teres	low	A C D
High tidal alluvial fan	Crustacea:	*Sesarma* spp	low	A C D G
		Uca sp	low	A C D
Tidal creek	Crustacea:	*Uca* spp	medium	A C D
		Macrophthalmus sp	medium	A C D
	Mollusca:	Teredinids	high	F
	Pisces:	gobioid fish	low/medium	A C D
Mid tidal alluvial fan	Crustacea:	*Sesarma* spp	low/medium	A C D E G
		Uca sp	low/medium	A C D
	Mollusca:	Teredinids	high	F
High tidal dune margin	Crustacea:	*Sesarma* spp	medium	A C D E G
		Uca	low	A C D
	Mollusca:	*Terebralia sulcata*	medium/high	I
		Terebralia palustris	medium/high	I
	Pisces:	gobioid fish	low/medium	A C D
High tidal lagoon	Crustacea:	*Sesarma* spp	medium	A C D E G
		Uca sp	low/medium	A C D
	Mollusca:	*Terebralia sulcata*	medium	I
		Terebralia palustris	medium	I
	Pisces:	gobioid fish	low/medium	A C D
Shoals	Crustacea:	*Mictyris* sp	medium/high	A C D
		Scopimera sp	medium/high	A C D
		Uca sp	low/medium	A C D
Limestone pavement		no fauna relevant to mangroves	—	—

1. fauna listed herein are those that have obvious direct relationship to mangrove ecology; fauna such as encrusting barnacles, oysters or algae grazing gastropods although potentially abundant, are not included. Avifauna and insect fauna also are not included.
2. high abundance: density greater than $10/m^2$
   medium abundance: density $1\text{-}10/m^2$
   low abundance: density less than $1/m^2$
3. A bioturbation: soil turnover affecting salinity and nutrients
   B bioturbation: soil mounding developing microscale soil salinity mosaics
   C aeration: function of open burrows and bioturbation structures to facilitate gas exchange
   D generation of conduits: function of burrows and bioturbation structures to facilitate hydrologic exchanges
   E seedling predation: predation of seeds, seedlings and saplings
   F wood boring
   G leaf degradation
   H leaf grazing
   I faeces production

scale geomorphic units with their distinctive substrate and stratigraphy also may function as discrete conduits for marine water flow or fresh water flow, both of which influence the salinity of the habitat.

Thus habitats are strongly linked to geomorphic unit. As a result, a medium geomorphic unit functions as a distinct habitat that is the product of tidal level, substrate and salinity. *Within* a geomorphic unit (or habitat) there also are internal gradients. These occur because:

(1) tidal level on a gradually rising shore provides a gradient of decreasing frequency-of-inundation;

(2) substrates may exhibit a gradient with grain-size or sediment abundance increasing or decreasing in a specific direction;

(3) salinity of groundwater/soilwater also shows a graded change dependent on tidal level (and hence a change in recharge and evaporation) and proximity to recharge of marine water (to seaward) or fresh water (to landward).

Mangrove habitats in the Dampier Archipelago may be classified at several scales (following Semeniuk 1985 p. 22). In this study region there are 2 appropriate scales i.e. large scale settings and medium scale settings.

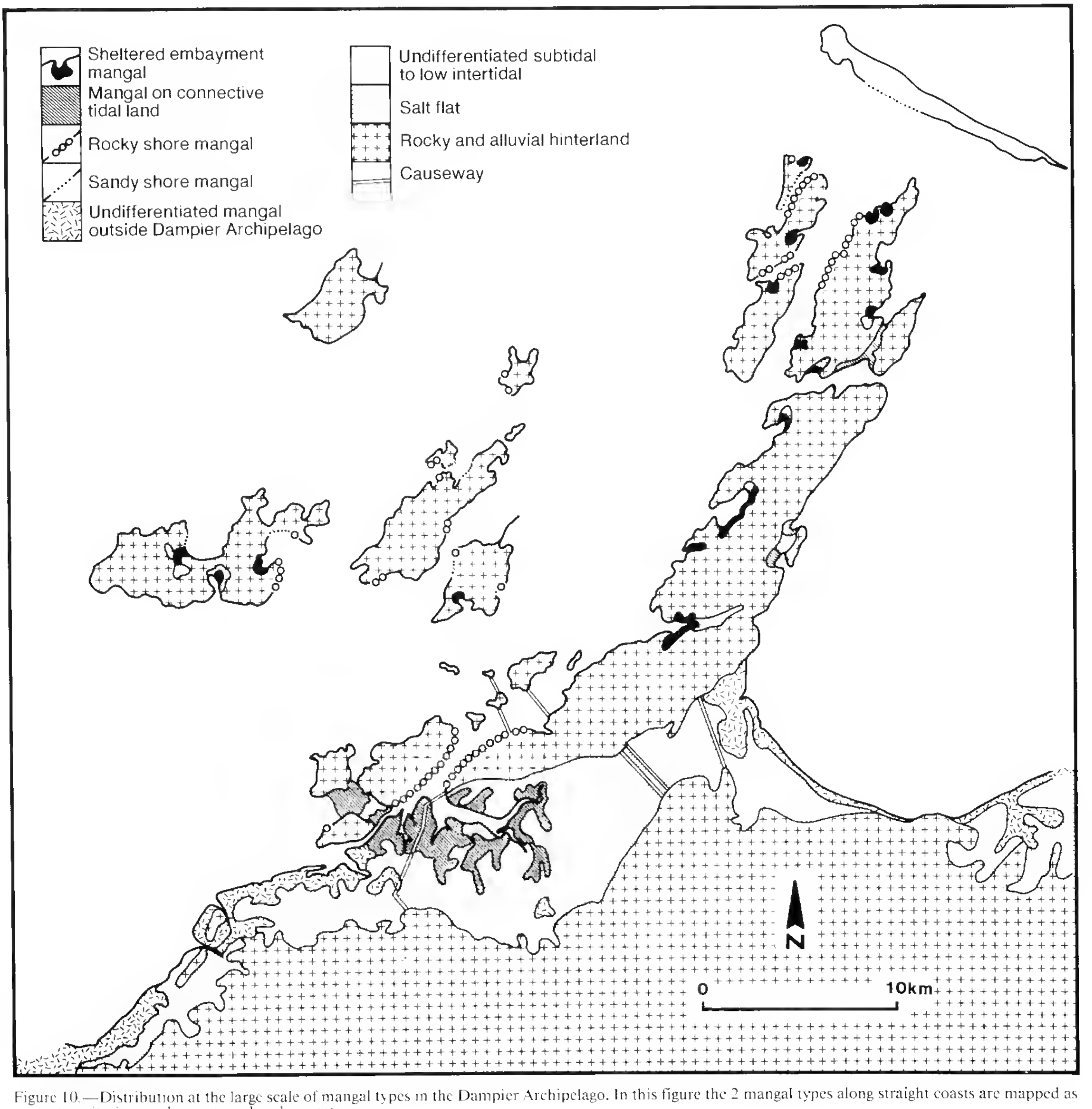

Figure 10.—Distribution at the large scale of mangal types in the Dampier Archipelago. In this figure the 2 mangal types along straight coasts are mapped as separate units, i.e. sandy coasts and rocky coasts.

At the large scale 3 categories of mangrove-vegetated coastal types are recognised (Fig. 10):

(1) Embayment types, which are probably the most important areas for mangroves in this region;

(2) Connective tidal-land types, which are the second most important mangrove systems in this region;

(3) Straight coasts composed of open rocky-bouldery shore types and open sandy beach-dune shore types.

Within each of the large scale mangrove settings there is the distinct suite of medium scale geomorphic units described on p. 36-38. These various geomorphic units are treated herein as distinct mangrove habitats since each geomorphic unit essentially has its own suite of physico-chemical parameters such as tidal level (frequency-of-inundation), substrate and salinity. However, boundaries between some geomorphic units also may function as discrete mangrove habitats because of the development of specific zones of mixing or overlap in factors such as sediment type or fresh water seepage or slope. Thus, for instance, where the salt flat on a muddy tidal flat adjoins a dune terrain, the zone of contact between the two units is a discrete mangrove habitat:— to seaward there is a salt flat devoid of mangrove, to landward there is the dune terrain with its terrestrial vegetation, and along the zone of contact there is a narrow mangrove habitat. In some cases a given geomorphic unit may occur at different tidal levels of the shore e.g. alluvial fans which predominantly occur in high tidal environments but some may penetrate seaward to mid tidal and low tidal shore levels. In these cases geomorphic units at the various tidal levels are distinguished as different mangrove habitats. Thus high tidal alluvial fans are distinguished from mid-tidal alluvial fans.

The mangrove habitats recognised in this study listed in order of their abundance and importance in supporting mangroves are as follows:

1. Muddy tidal flat
2. Sandy tidal flat
3. Rocky-bouldery shore
4. Spit and chenier
5. Beach
6. Hinterland margin
7. Gravel tidal flat
8. High tidal alluvial fan
9. Tidal creek
10. Mid-tidal alluvial fan
11. High tidal dune margin
12. High-tidal lagoon
13. Shoal
14. Limestone pavement

A description of these units and their features important to mangroves is provided in Table 5.

Synthesis

The edaphic features of mangrove environments in the Dampier Archipelago are the product of several *interacting* physical, chemical and faunal factors. These are:

(1) ancestral topography
(2) oceanographic aspect
(3) modern processes of sedimentation/erosion
(4) tidal slope
(5) stratigraphic sequence and substrates
(6) salinity regimes
(7) fauna effects.

These factors contribute to development of habitats that have distinct tidal level, substrates, salinity and fauna, all of which are significant in maintaining and regulating mangrove populations.

A summary of the development of habitats may also be approached from the point of view of marine processes and terrestrial processes acting on the archipelago shore. The main marine processes include daily to monthly tidal flooding, wave and tidal-current action, and fauna effects. These processes are influential in shaping environmental factors up to levels of mean high water spring tide. Thus, they influence the development of substrate types, gradients in substrate variation, sediment transport, the evolving stratigraphic sequence, frequency of flooding, water logging, salinity, oxygenation and bioturbation. The survival of mangroves and benthic fauna, their population maintenance and hence their zonation between mean sea level and mean high water spring are dependant largely on prevailing marine conditions. Terrestrial modifications generally have little or no influence on those environments dominated by marine processes.

The terrestrial processes on the higher portions of tidal flats include evaporation, desiccation, sedimentation, and freshwater seepage. The processes of evaporation and desiccation, together with infrequent tidal recharge, develop extremely hypersaline salinity regimes which culminate in the development of salt flats at the expense of mangroves and other biota. However, freshwater seepage along the edge of the hinterland and, in particular at the exit points of terrestrial drainage (eg high-tidal alluvial fans), provide a specialised habitat where there is a local occurrence of mangroves and other biota because of a regime of lower salinity (Semeniuk, 1983). Thus an important factor in the maintenance of mangroves and fauna along the edge of the hinterland and on high tidal alluvial fans is the terrestrial process of freshwater seepage.

Each of the medium scale to small scale geomorphic units (or mangrove habitats) if viewed from this perspective can be seen as distinct products with their own internal suite of processes and gradients that provide distinct habitats that support mangroves. Special mention should be made of the transgression of spits across a tidal flat surface because in effect there may be developed two intersecting gradient systems. As a result spits have a more complex array of mangrove species inhabiting them.

Mangrove Vegetation

Species Pool

Only six species of mangrove occur in the littoral zone of the area (Semeniuk *et al.* 1978, Semeniuk 1983). In alphabetical order, these are:

	Species	*Family*
(1)	*Aegialitis annulata* R. Br.	PLUMBAGINACAE
(2)	*Aegiceras corniculatum* (L.) Blanco	MYRSINACEAE

(3) *Avicennia marina* (Forsk.) Vierh. AVICENNIACEAE

(4) *Bruguiera exaristata* Ding Hou RHIZOPHORACEAE

(5) *Ceriops tagal* (Perr.) C. B. Rob. RHIZOPHORACEAE

(6) *Rhizophora stylosa* Griff. RHIZOPHORACEAE

This low species richness of mangrove, compared with that of the humid tropics (Saenger et al. 1977, Tomlinson 1986), is representative of northwestern Australian coastline and is typical of mangrove assemblages that occur in tropical arid climates (Semeniuk 1983). Notes on habit, relative abundance, and associations of these species in the Dampier Archipelago follow.

TABLE 5

Mangrove Habitats: A Summary of Their Important Features

Habitat	Description	Main Gradients Important for Mangrove Zonation	Comments on Features that Maintain Habitats & Gradients
Muddy tidal flat	gently inclined surface between MSL and HAT, underlain mainly by mud	frequency of inundation; salinity	habitat surface is maintained by sedimentation/erosion; salinity is maintained by marine water recharge/discharge, seasonal meteoric recharge and evaporation
Sandy tidal flat	gently inclined surface between MSL and HAT underlain mainly by sand and muddy sand	frequency of inundation; salinity	habitat surface is maintained by sedimentation/erosion; salinity is maintained by marine water recharge/discharge, seasonal meteoric recharge and evaporation
Rocky-bouldery shore	steep to moderately inclined surface underlain by bedrock or boulder/pebble sheet	frequency of inundation; salinity	habitat surface is maintained by erosion/sedimentation; shallow soil or no soil; marked surface water runoff; salinity maintained by marine water recharge, efficient discharge and evaporation
Spits and cheniers	steep to moderately inclined surface underlain by sand, shelly sand and muddy sand	frequency of inundation; salinity; substrate grainsize; drainage	habitat surface is maintained by sedimentation/erosion; salinity maintained by marine water recharge, efficient discharge, evaporation and periodic freshwater seepage
Beach	steep surface underlain by sand	frequency of inundation; drainage	habitat surface is maintained by sedimentation/erosion, salinity is maintained by efficient recharge/discharge of marine water
Hinterland margin	moderately steep to gently inclined surface underlain by muddy sand/gravel	salinity; substrate grainsize	habitat is developed and maintained by extensive freshwater seepage, and sediment sheetwash off the hinterland
Gravel tidal flat	gently inclined surface between MSL and HAT underlain by gravel, sandy gravel and muddy gravel	frequency of inundation; salinity	habitat is maintained by erosion/sedimentation; salinity regimes maintained by marine water recharge, discharge and evaporation
High tidal alluvial fan	gently inclined surface underlain by muddy sand/gravelly sand, and gravel	salinity; substrate grainsize	habitat is developed and maintained by extensive freshwater seepage, and sediment input along stream/creek channel
Tidal creek (bank)	steep to moderately inclined muddy surface between MSL and HWN	frequency of inundation; salinity; drainage	habitat surface is maintained by erosion; steep banks and bio-excavation/burrows ensure rapid drainage
Mid-tidal alluvial fan	gently inclined surface underlain by muddy sand/gravelly sand, and gravel	frequency of inundation; salinity; drainage	habitat is developed and maintained by extensive freshwater seepage, and sediment input along stream/creek channel; marine water recharge/discharge
High tidal dune margin	narrow gently inclined surface at margin of dunes	salinity	habitat and surface maintained by sheet wash off dunes onto salt flat, salinity regime maintained by seepage of seawater/freshwater from dune reservoir
High-tidal lagoon	linear depressions developed at c. HWS	salinity; drainage	habitat formed by impounding of drainage channel; seepage of freshwater or seawater from dunes and hinterland maintains the salinity regime
Shoal	hummocky muddy surface at c. MSL	distinct gradients not evident	habitat surface is maintained by sedimentation alternating with erosion
Limestone pavement	planed surface of limestone with local boulder/slab accumulations	frequency of inundation	habitat is maintained by constant sediment winnowing

Notes on species

Aegialitis annulata, commonly known as the Club Mangrove, is a small slender shrub up to 1 m high. The species most commonly occurs scattered as an understorey component in mixed associations between MSL and HWS or sandy beach shores; it also occurs scattered as an understorey component to *Avicennia* forests and scrub on *gravel substrates* at levels of HWS and occurs mixed with *Avicennia* and *Ceriops* at HWS on *spit margins* and *beaches*. While the species could not be considered regionally or locally abundant, it is nonetheless well distributed and most embayments have some individuals.

Aegiceras corniculatum is known internationally as the River Mangrove because of its tendency to line those rivers and creeks with a fresh water influx. It is a bushy shrub up to 2 m high. In the Dampier Archipelago the species is not associated with freshwater influx but is most commonly developed at *c.* MSL on *creek banks* and *shoals*. In these habitats the species forms a closed heath structure or alternatively occurs in association with *Avicennia* and/or *Aegialitis*. Locally it also occurs in mixed association on mid tidal levels of sandy beach shores. The species is not regionally or locally abundant but can be considered to be widely but sporadically distributed.

Avicennia marina the White Mangrove, is the *most widespread, the most abundant, and physiognomically the most variable* of species in the Dampier Archipelago. It occurs as a medium tree up to 6 m high forming closed low forests, it forms closed scrub 3-4 m high at HWN to HWS and, where salinity of groundwater/soilwater is excessive, it can form a low heath up to 0.5 m high at HWS. Physiognomically it varies from bushy shrubs, to multistemmed shrubs, to columnar small trees, to recumbent and gnarled trees. *Avicennia* can occur *virtually in any habitat* encompassing the full mangrove tidal range from MSL to HAT; as such it can form pure stands at the limits of its tidal range (where other species are eliminated), or can occur with other species in mixed stands.

Bruguiera exaristata, commonly called the Ribbed-fruited Orange Mangrove overseas, is a slender shrub to small tree up to 5 m high, buttressed at the base. Its most common occurrence is within mangrove scrub along *sandy beach shores* and the *margin of spits* at levels of HWS, where it occurs in association with *Avicennia* and *Ceriops*. It also may occur in the *interior of mangrove forests* at level of HWN in association with *Rhizophora*. The species, although widespread throughout the Dampier Archipelago, is not particularly abundant at any given site.

Ceriops tagal is commonly called the Yellow-leaved Spurred Mangrove. It occurs as a slender, columnar, buttressed shrub up to 2.5(-3.0) m high. The species occurs at levels of HWS along *sandy beach shores, margins of spits*, along *gravelly hinterland margins* and on *high tidal alluvial fans, the headwaters of tidal creeks* and, locally, on the high tidal portion of *muddy tidal flats*. It occurs locally as pure stands of closed or open scrub but more commonly it is associated in scrub with *Avicennia* and *Bruguiera*. Although not particularly abundant at any given site it is nonetheless quite a widespread species.

Rhizophora stylosa commonly termed the Red Mangrove, occurs as a shrub to tree up to 6-7 m high. Near levels of HWN on *muddy tidal flats* it forms dense closed forests of pure stands. Elsewhere such as on *rocky shores, sandy tidal flats*, or *sandy beach shores* it occurs at about HWN as a shrub subordinant to other species. The species is widespread and second in abundance only to *Avicennia*, although in some embayments it may exceed the abundance of *Avicennia*.

Floristic and structural classification

In categorising the mangrove vegetation of the Dampier Archipelago an approach utilising floristics and structure was adopted. The structural categories follow that of Specht (1981) with the following modifications. Vegetation with heights of 0.25-1.5 m is termed low shrub and forms heath; those plants taller than 1.5 m but less than 5 m are tall shrubs and form scrub or shrubland; and those with heights of 5-7 m are termed trees and form forests. The term "overmature" used in this paper refers to large diameter trees that have hollowed trunks and that have become recumbent and gnarled.

The floristic categories are based on numerically and structurally dominant species within the assemblages. Since there are only 6 species of mangroves in the region, the categorisation of the vegetation only on floristics becomes relatively simple. Furthermore many of the categories are comprised of monospecific stands.

A description of the floristic/structural units is provided in Table 6. Typical distribution of the units within the medium scale habitats is shown in Table 7. The main floristic and structural categories of mangroves recognised in the region are:

1. *Avicennia* forest (A1)
2. *Avicennia* scrub (A2)
3. *Avicennia* heath (A4)
4. *Avicennia-Aegialitis* scrub (AAe2)
5. *Avicennia-Ceriops* scrub (AC2, CA2)
6. *Ceriops-Bruguiera-Avicennia* scrub (CBA2, ABC2, BCA2)
7. *Rhizophora* forest (R1)
8. *Rhizophora* scrub (R2)
9. *Rhizophora-Bruguiera* scrub (RB2)
10. *Avicennia* shrubland (A3)
11. Mixed scrub (eg ABRC2).

The mangrove assemblages

The mangrove flora of the Dampier Archipelago is treated as assemblages that inhabit discrete habitats. The approach involves the following procedure:

1. the identification of tracts of mangrove formations within a large scale geomorphic setting (Figure 6), such as extensive occurrencies in sheltered embayments, or as strips along a rocky coast.
2. the delination of habitats within this system based on medium scale geomorphology (Figure 7), substrate, and salinity.
3. the assignment of assemblage nomenclature to vegetation, based on its occurrence on a given habitat unit.
4. the documentation of the structure and floristics of the vegetation units and zones within each assemblage.

TABLE 6

Description and Distribution of Vegetation Types in Mangals of the Dampier Archipelago

Vegetation type*	Structure and floristics	Distribution within habitat and assemblage
A1	Closed forest of mature, gnarled sometimes recumbent *Avicennia marina* trees, 5-6 m tall.	Occurs most commonly as a narrow band 1 or 2 trees wide at the seaward edge (MSL) of the main mangrove belt of the sandy tidal flat assemblage. It may also occur in the same manner on muddy tidal flats.
A2	Closed scrub of mature gnarled, recumbent or multi-stemmed shrubs of *Avicennia marina*, from 1.5 m to less than 5 m tall; may become open in more saline situations such as MHWS.	The most widespread vegetation unit within the archipelago mangroves. It forms the main mangrove belt on sandy tidal flats, gravelly tidal flats and mid tidal alluvial fans, comprises the high tidal lagoon assemblage, occurs on muddy tidal flats between MHWN and MHWS, and commonly occurs on sandy beaches.
A3	Closed to open shrubland of multi-stemmed shrubs of *Avicennia marina*, from 1.5-2.5 m tall.	Quite widespread and occurs in the more saline extremes of, nutrition poor habitats such as: the periphery of salt flats (i.e. the landward edge of the main sandy tidal flat assemblage); high tidal dune margin; hinterland margin, high tidal alluvial fan; the seaward most portions of spits which extend across the tidal gradient. This unit also most commonly comprises the gravelly tidal flat assemblage.
A4	Open heath of mature multi-stemmed shrubs of *Avicennia marina*, less than 1.5 m tall.	Not widespread but occurs most commonly at the landward edge of the main *Avicennia* belt on sandy tidal flats (i.e. adjacent to salt flats) and rarely on high tidal alluvial fans, and the landward most edge of gravelly and muddy tidal flat mangrove stands.
AR2 or RA2	Closed scrub of mature *Avicennia* and *Rhizophora* shrubs, from 3 m to less than 5 m tall. The *Avicennia* occur as mature recumbent or multi-stemmed individuals. *Rhizophora* occurs as mature single stemmed or laterally spreading multi-stemmed individuals.	Comprises the tidal creek assemblage and also occurs at the seaward edge of the main mangal belt on muddy tidal flats, either seaward to, or instead of an A1 vegetation unit. Patches of RA2 or AR2 also consistently occur within the central portions of mid tidal alluvial fans and on larger mud shoals. The unit also occurs on rocky shores and on gravelly tidal flats.
Ae2	Scrub of *Aegiceras* to 2 m tall with an understorey of *Aegialitis* less than 1 m tall	Occurs on the sandy shoal habitats. This habitat and vegetation unit are not widespread.
AAe2	Scrub of multi-stemmed *Avicennia* shrubs 1.5-2.5 m tall with an understorey of *Aegialitis*, less than 1 m tall, or *Aegiceras* shrubs 1.5 m tall.	Noted on rocky shores, gravelly shores and sandy tidal flats. The unit is not widespread.
AAe3	Open shrubland of multi-stemmed *Avicennia* shrubs 1.5-2 m tall with an understorey of *Aegialitis* or *Aegiceras*.	Occurs on rocky shores and sandy shoals. It is not widespread.
AAe4	An open to closed heath of multi-stemmed *Avicennia* shrubs with an understorey of *Aegialitis* shrubs to 1.5 m tall.	May occur as a small patch on the middle of a sandy tidal flat to the landward and seaward surrounded by A2. This unit was noted once during the study.
ABCAe2 & CBAAe2	Closed scrub of *Avicennia*, *Bruguiera* and *Ceriops* shrubs 2.5-3 m tall, with an understorey of *Aegialitis* shrubs less than 1 m tall.	Includes an unusually diverse array of species and was noted to occur on a rocky shore habitat and a beach.
ACAe2	Closed scrub of *Avicennia* and *Ceriops* shrubs to 2 m tall with an understorey of scattered *Aegialitis* shrubs less than 1 m tall.	Occurs as a narrow belt (5 m wide) along a high tidal dune margin flanked by A3/A2 at the seaward edge.
AC2 & CA2	Closed scrub of multi-stemmed *Avicennia* and columnar *Ceriops* shrubs 1.5-2 m tall.	Occurs on spits and cheniers, high tidal dune margin and rarely on rocky shores.
AAeR2	Scrub of *Avicennia* and *Rhizophora* shrubs, 2.5 m tall, with an understorey of *Aegialitis* shrubs, less than 1 m tall.	Not widespread: noted as a small shoal at the seaward front of the main mangrove belt in Searipple Passage.
R1	Closed forest of mature primarily single trunked, *Rhizophora* trees, 5-6 m tall.	Not widespread and may rarely occur as a thin belt of one to two trees wide along the seaward edge of the muddy and sandy tidal flats.
R2	Closed scrub of mature, multi-stemmed and intertwining, or sometimes single trunked, *Rhizophora* shrubs generally 2-4 m tall. Rare *Bruguiera* shrubs may also occur in the unit.	Consistently occurs as a seaward zone between MSL and MHWN on muddy tidal flats. It also rarely occurs as a seaward zone on sandy tidal flats. An abrupt contact consistently occurs at its landward edge with an A2 unit. An RA2 or R1 unit sometimes occurs at its seaward edge.
RB2	Closed scrub of mature, multi-stemmed and intertwining, or sometimes single trunked, *Rhizophora* shrubs, with common to occasional columnar *Bruguiera* trees 2-4 m tall.	Occurs as a distinct zone between MSL and MHWN on muddy tidal flats, flanked to its seaward edge by a narrow RA2 belt and its landward edge by the A2 zone. Although scattered *Bruguiera* trees (shrubs) frequently occur, but not always, in the R1 vegetation unit they are not generally abundant enough to include in a map unit.

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TABLE 6

Description and Distribution of Vegetation Types in Mangals of the Dampier Archipelago—*continued.*

Vegetation Type*	Structure and floristics	Distribution within Habitat and Assemblage
B2	Closed scrub of columnar *Bruguiera* trees 2-3 m tall.	Occurs occasionally as a landward zone from 1 to 10 trees wide on the spit or chenier habitat and was also noted as a landward zone on a sandy beach. It may however be flanked by a C2 belt at its landward edge.
B3	Shrubland of columnar *Bruguiera* shrubs 2-2.5 m tall.	Occurs on a high tidal gravelly apron immediately landward of a mangrove vegetated sandy tidal flat; recorded once in the study areas.
C2	Scrub of columnar *Ceriops* shrubs 1.5 m tall.	May occur on the high tidal alluvial fan habitat, as a narrow (1-3 trees wide) belt at the landward edge of beach and chenier habitats, and rarely on the hinterland fringe habitat.
C3	Shrubland of columnar *Ceriops* shrubs 1.5 m tall.	May occur on the high tidal alluvial fan habitat. It is not common.
BAC2 & BCA2 & ACB2	Closed scrub of mixed columnar *Bruguiera* and *Ceriops* shrubs with multi-stemmed *Avicennia* shrubs 1.5-2.5 m tall.	Commonly occurs on the higher tidal zone (i.e. within the zone of greatest freshwater seepage) of spits and cheniers. ACB2 was also noted on the high tidal portion of a gravelly tidal flat in King Bay.
BA2	Closed scrub of *Bruguiera* and *Avicennia* shrubs 1.5-2.5 m tall.	Noted to occur on the chenier habitat.
ABRC2	Closed scrub of *Avicennia, Bruguiera, Rhizophora* and *Ceriops* shrubs to 2 m tall.	Occurs on some sandy beaches, and spits, and was noted on a gravelly tidal flat.
RCBA2/4	Closed to open scrub of *Rhizophora, Ceriops,* and *Avicennia* and *Bruguiera* 2 m tall.	Occurs on a high tidal alluvial fan on Angel Island. The various species form zones several trees wide, with *Rhizophora* at the seaward edge and *Avicennia* at the landward most edge of the vegetated portion of the high tidal alluvial fan.
RBA3	Closed shrubland of *Rhizophora* and *Bruguiera* columnar shrubs and multi-stemmed *Avicennia* shrubs 2-2.5 m tall.	Not common; occurs on a spit.
ABR2	Scrub of *Avicennia, Bruguiera* and *Rhizophora* shrubs 2-2.5 m tall.	Not widespread; noted on a rocky shore.
CA3	Shrubland of mature columnar *Ceriops* and *Avicennia* recumbent and multi-stemmed shrubs 1.5 m tall.	Occurs on high tidal alluvial fan and rarely on rocky shores.

* A = *Avicennia marina;* B = *Bruguiera exaristata;* C = *Ceriops tagal;* Ae = *Aegialitis annulata* or *Aegiceras corniculatum;* R = *Rhizophora stylosa.* Order of letters in the abbreviated nomenclature indicates relative abundance of species; thus ABC indicates *Avicennia* > *Bruguiera* > Ceriops. The numerical postscripts 1, 2, 3, 4 refers to structure of the unit: 1 = forest; 2 = scrub (closed or open); 3 = shrubland (closed or open); 4 = heath (closed or open).

Viewing floristic composition alone would provide little differentiation of the underlying patterns within assemblages because in reality only a few species contribute to the mangrove formations. Considering vegetation structure *and* floristics together also does not fully exemplify the various responses of vegetation to different habitats. Ideally, a classification of vegetation within the compositionally simple systems of the Dampier Archipelago should be based on the following features:

- floristics
- structure
- physiognomy of individuals
- population dynamics and maintenance processes.

However, a comprehensive categorisation of mangrove vegetation using such features at this stage is premature, because the complete data for the population dynamics and maintenance are not available.

The approach adopted here therefore is to recognise that a suite of species inhabits a discrete habitat and that consequently, physico-chemical and biotic forcing factors eliminate, regulate and maintain the various species resulting in (1) a differential distribution of species, (evident as compositional zonation), (2) a variety of physiognomic types (evident as physiognomic and structural zonation) and (3) variation in population maintenance processes (evident as physiognomic and structural zonation). Arbitrarily choosing either compositional or structural zones and nominating them as assemblages or "communities", or alternatively combining them as floristic/structural zones, is merely identifying vegetation responses to a number of underlying environmental factors.

In this paper therefore an assemblage is recognised as inhabiting a given habitat, and thereafter the various floristic, structural and physiognomic zones that occur in the assemblage are described within a framework of physico-chemical gradients *within* the habitat.

TABLE 7

Occurrence of Floristic/Structural Vegetation Categories in Relationship to Habitats[1]

Habitat Type	VEGETATION		
	Vegetation type occurring on habitat	Vegetation type less commonly occurring on habitat	Vegetation type occurring at least once on habitat
Muddy tidal flat	R2, A2	A3	A4, AR2, RA2, RB2, R1, AAe4, AAeR2
Sandy tidal flat	A2, A3	A1, A4	RA2, R2, AAe2, AC2, AR2, R1
Rocky/bouldery shore	A3		A2, AR2, RA2, AAe2, ABCAe2, AC2, B3, ABR2
Spits and cheniers	A3	A2	RBA3, AC2, B2, BA2, BAC2, BCA2, BRAC2, CA2
Beach	A2, A3		B2, C2, CBAAe2, ABRC2
High tidal lagoon	A2		A3
High tidal dune margin	A3		RA2, A2, ACAe2, C2
Tidal creek	AR2, R2		
Mid tidal alluvial fan	A2, A3	R2, CA3	RA2, A1, AR2, C3
High tidal alluvial fan	A3		A2, C2, A4, C3, RCAB2
Hinterland margin	A3	A2	C2, CA2
Limestone pavement	A3	A2	
Shoals	AAe2, AAe3, A2, A3		
Gravelly tidal flat	A2	A3	R2, CA3, BRAC2, AR2, ACB2, AAe3, AAe2, A4

[1] Note that the ranking of vegetation units on a given habitat is according to their presence or absence only and not on their distribution across that habitat. For example A1 (*Avicennia marina* forest) occurs usually on sandy tidal flats although it occurs only as a narrow seaward band and is not areally significant.

Although the mangrove assemblages are named after their habitat, it should be stressed that terms such as "muddy tidal flat assemblage" is intended to convey a meaning of: "assemblages that inhabit muddy tidal flats". In order of abundance the assemblages are:

1. Muddy tidal flat assemblage
2. Sandy tidal flat assemblage
3. Rocky-bouldery shore assemblage
4. Spit and chenier fringe assemblage
5. Sandy beach assemblage
6. Hinterland fringe assemblage
7. Gravelly tidal flat assemblage
8. High tidal alluvial fan assemblage
9. Mid-tidal alluvial fan assemblage
10. Tidal creek assemblage
11. High tidal dune margin assemblage
12. High-tidal lagoon assemblage
13. Shoal assemblage
14. Limestone pavement assemblage.

Description of assemblages

The mangrove assemblages of Dampier Archipelago are described below in the following format:

- Distribution and occurrence
- Main physico-chemical gradients within the habitat
- Composition of assemblage
- Physiognomy and structure of assemblage
- Zonation in relation to gradients

Data on the structure, composition and abundance of species within the assemblages are described below and in the following figures. Figures 11-22 present maps of habitats, assemblages and vegetation distribution. The maps are selected from key areas that illustrate the variability of mangrove habitats in the Dampier Archipelago region. These maps also illustrate the marked local heterogeneity within a given area. In addition, Figures 23-30 illustrate cross-sections along selected transects from the areas mentioned above.

These cross-sections present information on a range of geomorphic, physico-chemical and vegetation features. These figures also present quantitative information on mangrove abundance. These quantitative data form the basis for the description of relative abundance and zonation as presented in the text following, for the identification of the floristic structural units as described in Tables 6 and 7, and for the information presented in summary form in Figure 31. A summary of the main vegetation features of each assemblage is presented in Table 8.

1. Muddy tidal flat assemblage

Distribution: The muddy tidal flat assemblage inhabits the inclined surface of the main tidal mud wedge (Figs 12, 14, 15, 20, 21 and 22). As such it is a common and extensive unit. It is generally a wide unit ranging in width from *c.* 100 m to 1 000 m depending on the size of the tidal flat and embayment in which it occurs.

Main physico-chemical features and gradients within habitat: The muddy tidal flat is an inclined surface (1:1 000-1:5 000) underlain by substrates of bioturbated mud which grades from thixotropic, burrowed and root structured at *c.* MSL to firm, desiccated/plastic homogenous/root-structured and burrow-punctured at MHWS. Much of the tidal water recharge is into burrows, root conduits and ped boundaries, otherwise excess water sheet flows off the surface. Bioturbation is important and results in the recycling of soils, as well as aeration and groundwater recharge/mixing. Salinity of groundwater and soil water show gradients of *c.* 45‰ at MSL to *c.* 90-100‰ at MHWS. Frequency of flooding varies from twice daily at MSL to fortnightly at levels above MHWS.

Composition, zonation and structure of assemblage (Figs 24, 27 and 30): The muddy tidal flat assemblage is predominantly composed of three species. It is the most widely developed assemblage in this area and is zoned, with distinctive species occurring at various tidal levels across the tidal flat. The zonation and structure of the assemblage are:

(1) The most seaward zone at *c.* MSL is a scrub (or forest) of mature recumbent and overmature *Avicennia*; the contact with the next zone is usually sharp.

(2) closed scrub (or low forest) of *Rhizophora* and scattered *Bruguiera* where salinities are 45-55‰

(3) closed scrub of *Rhizophora*

(4) closed scrub of *Avicennia* grading landward to closed heath or shrubland of *Avicennia*.

(5) the salt flat.

If the assemblage directly adjoins a rocky hinterland then the scrub of *Avicennia* may contain an understorey of scattered *Ceriops* and *Aegialitis*.

TABLE 8

Summary of Compositional and Physiognomic features and zonation within assemblages

Assemblage	Main Vegetation Zones
Muddy tidal flat	well zoned *Avicennia* and *Rhizophora* scrub
Sandy tidal flat	physiognomically zoned *Avicennia* forest, scrub or heath
Rocky bouldery shore	generally unzoned *Avicennia* shrubland or scrub; a scrub of mixed species may also occur
Spits/cheniers	generally zoned *Avicennia* shrubland, *Ceriops* scrub, *Bruguiera* scrub and *Avicennia* scrub
Sandy beach	mainly *Avicennia* scrub mixed with *Ceriops*, *Bruguiera*, *Aegialitis* and *Aegiceras*
Hinterland fringe	generally *Avicennia* scrub or shrubland
Gravel flat	generally *Avicennia* scrub
High tidal alluvial fan	*Avicennia* and *Ceriops* or *Avicennia* shrubland or scrub
Mid tidal alluvial fan	physiognomically zoned *Avicennia* forest and scrub with patches of *Rhizophora* scrub
Tidal creek	*Avicennia* and/or *Rhizophora* scrub
High tidal dune margin	generally *Avicennia* scrub or shrubland
High tidal lagoon	*Avicennia* scrub or shrubland
Shoal	*Aegiceras* scrub with understorey of *Aegialitis*
Limestone pavement	*Avicennia* shrubland

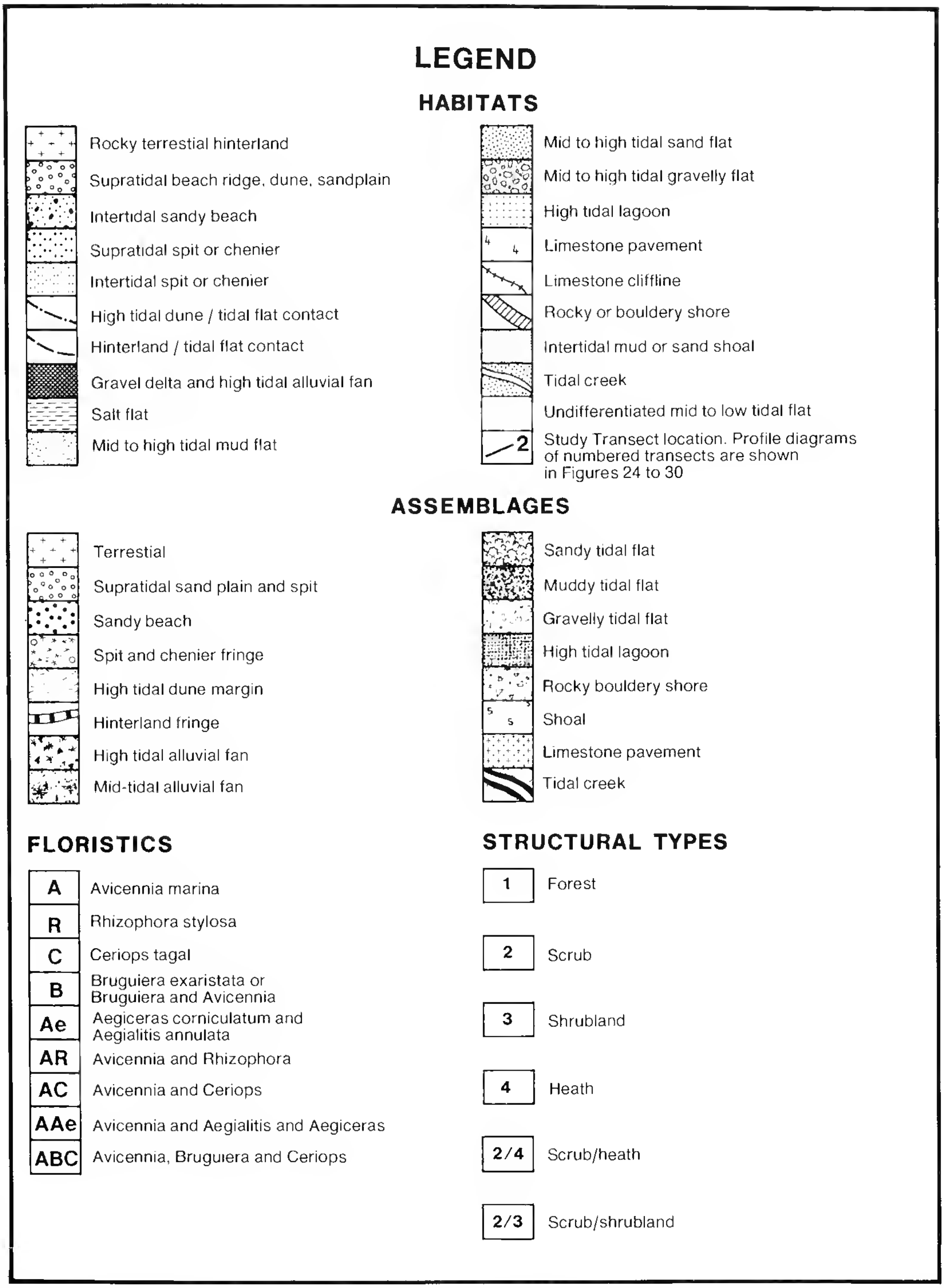


Figure 11.—Legend to habitat, assemblage and vegetation maps shown in Figures 12-22. The location of maps is shown in Figure 2. Note that: (1) the order that plant name symbols are written on a given map unit (eg AC2 versus CA2) indicates the order of abundance of the component species; (2) the A3 and A4 vegetation units may be associated with microscale development of salt flat. If a habitat pattern appears on the vegetation map it indicates that the habitat is bare of mangroves.

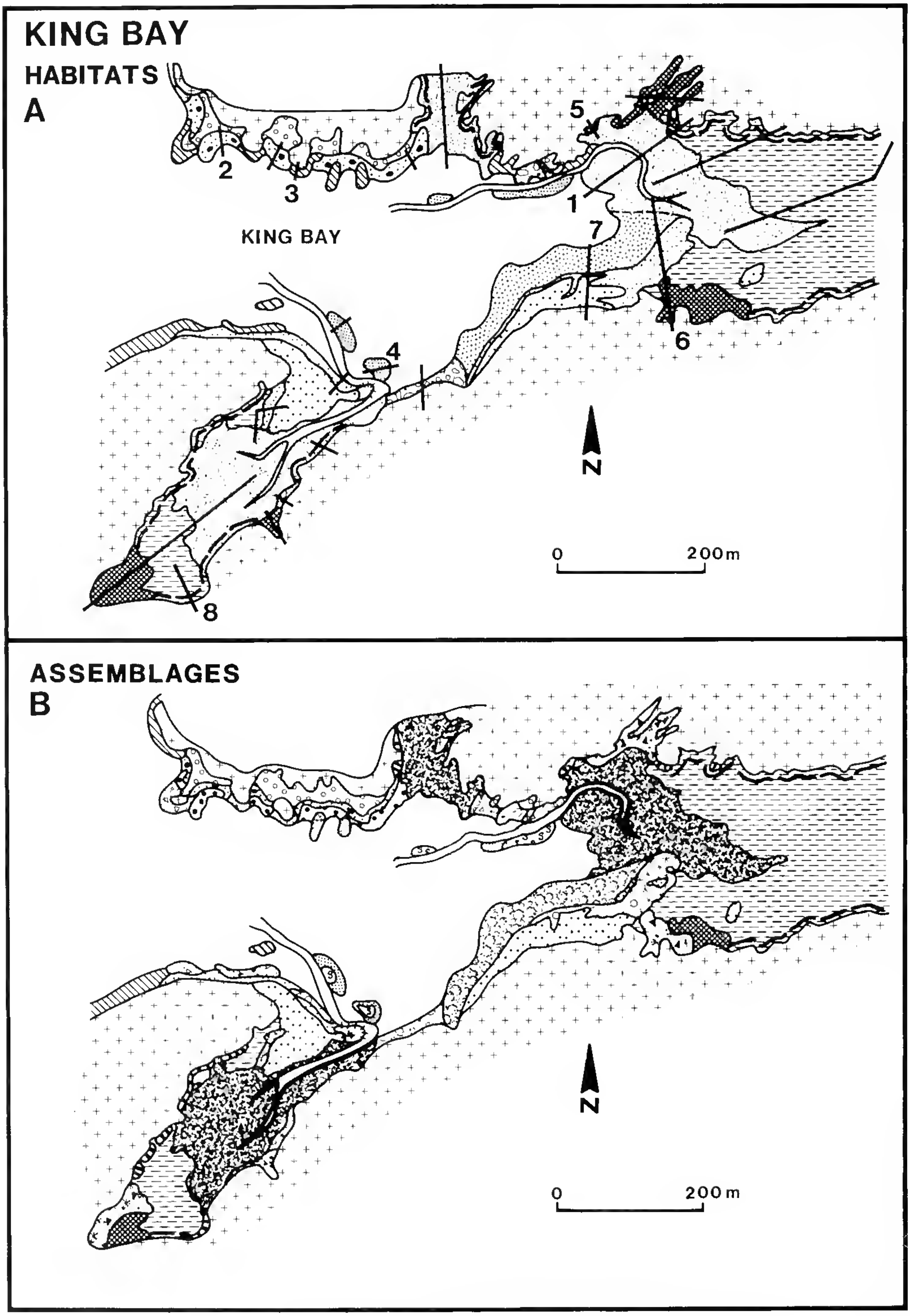


Figure 12.—King Bay. A. Habitat map, B. Vegetation assemblage map.

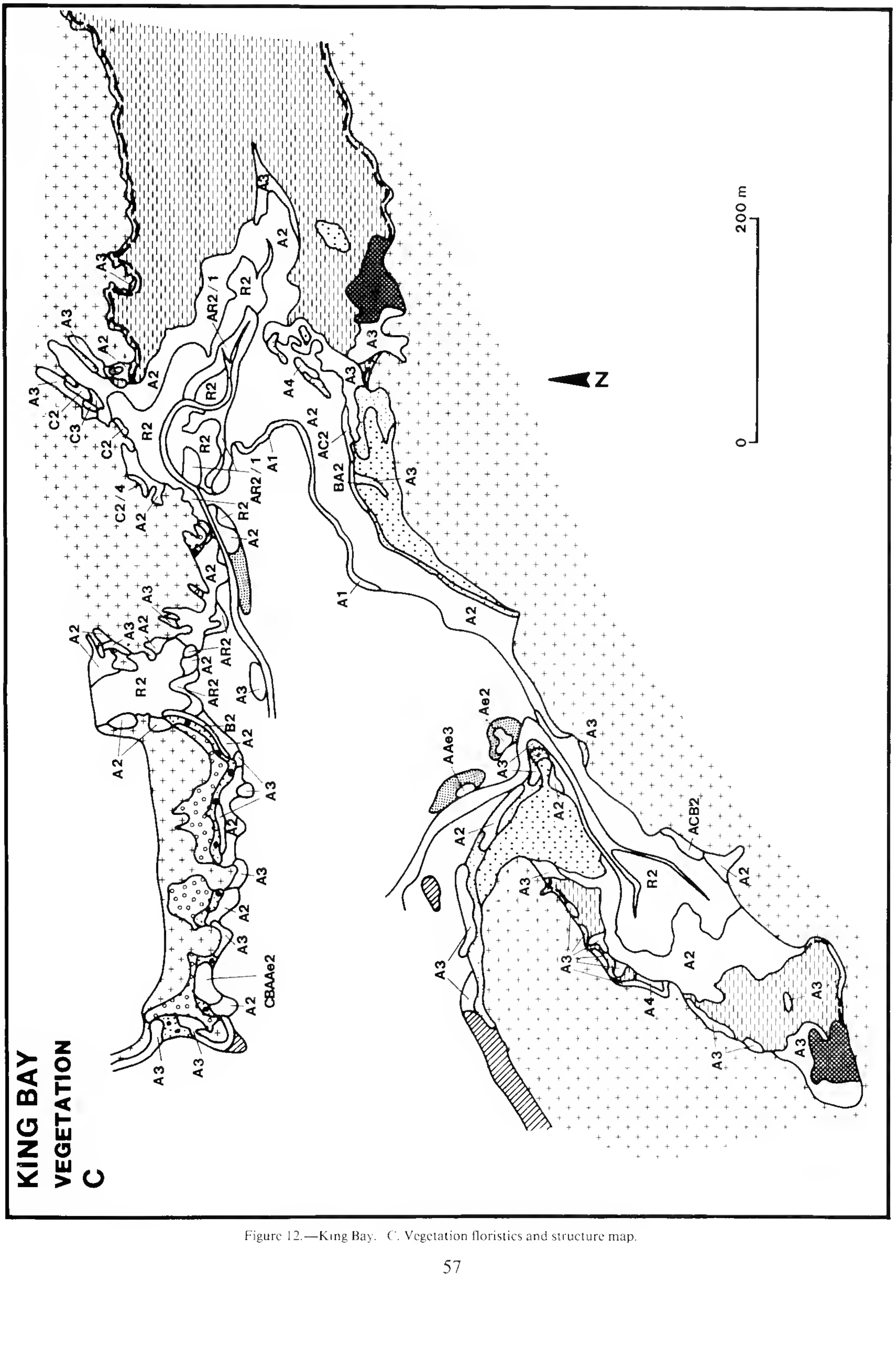


Figure 12.—King Bay. C. Vegetation floristics and structure map.

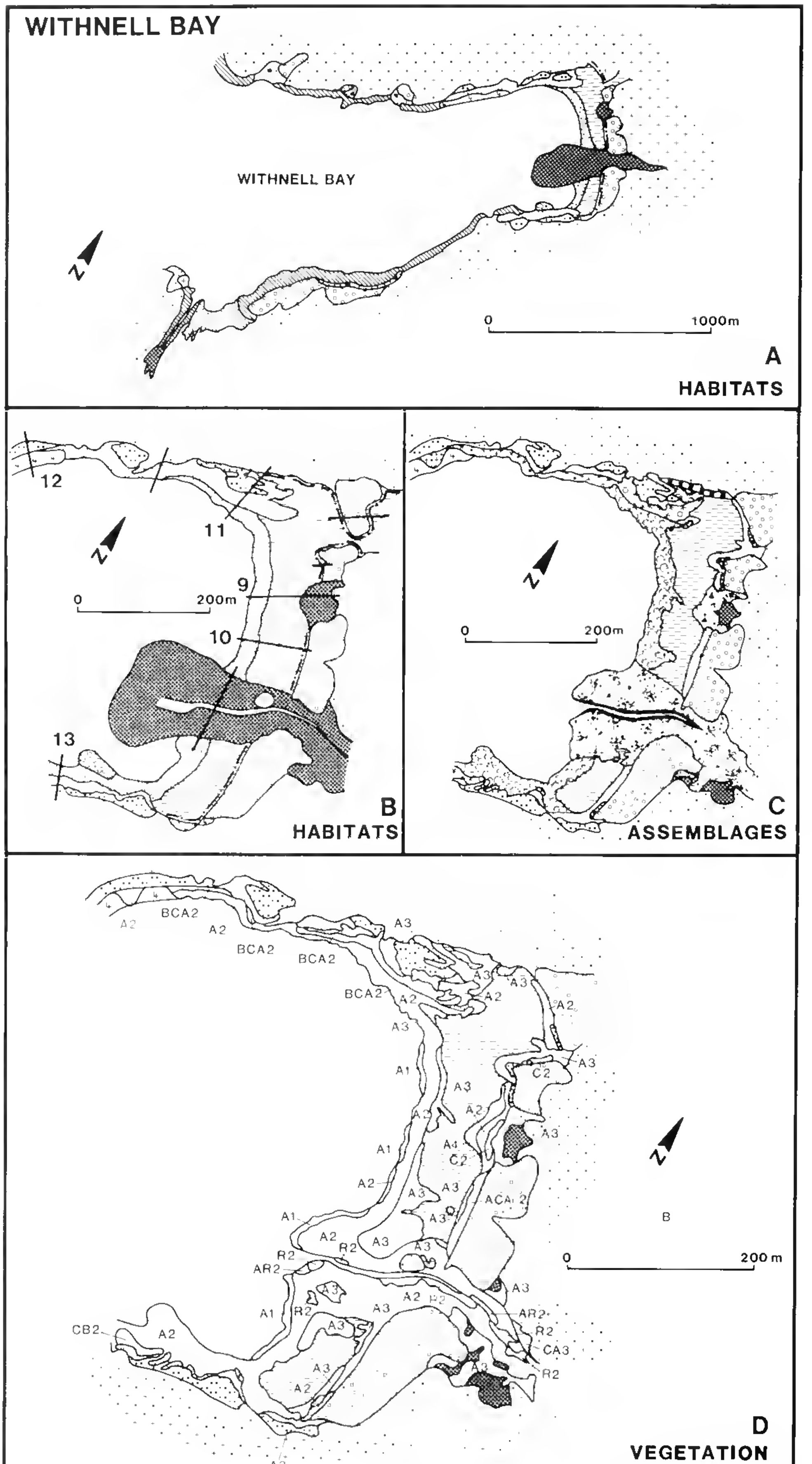


Figure 13.—Withnell Bay. A. Overall habitat map of Withnell Bay. B. Closeup of northeastern Withnell Bay. C. Vegetation assemblage map. D. Vegetation floristics and structure map.

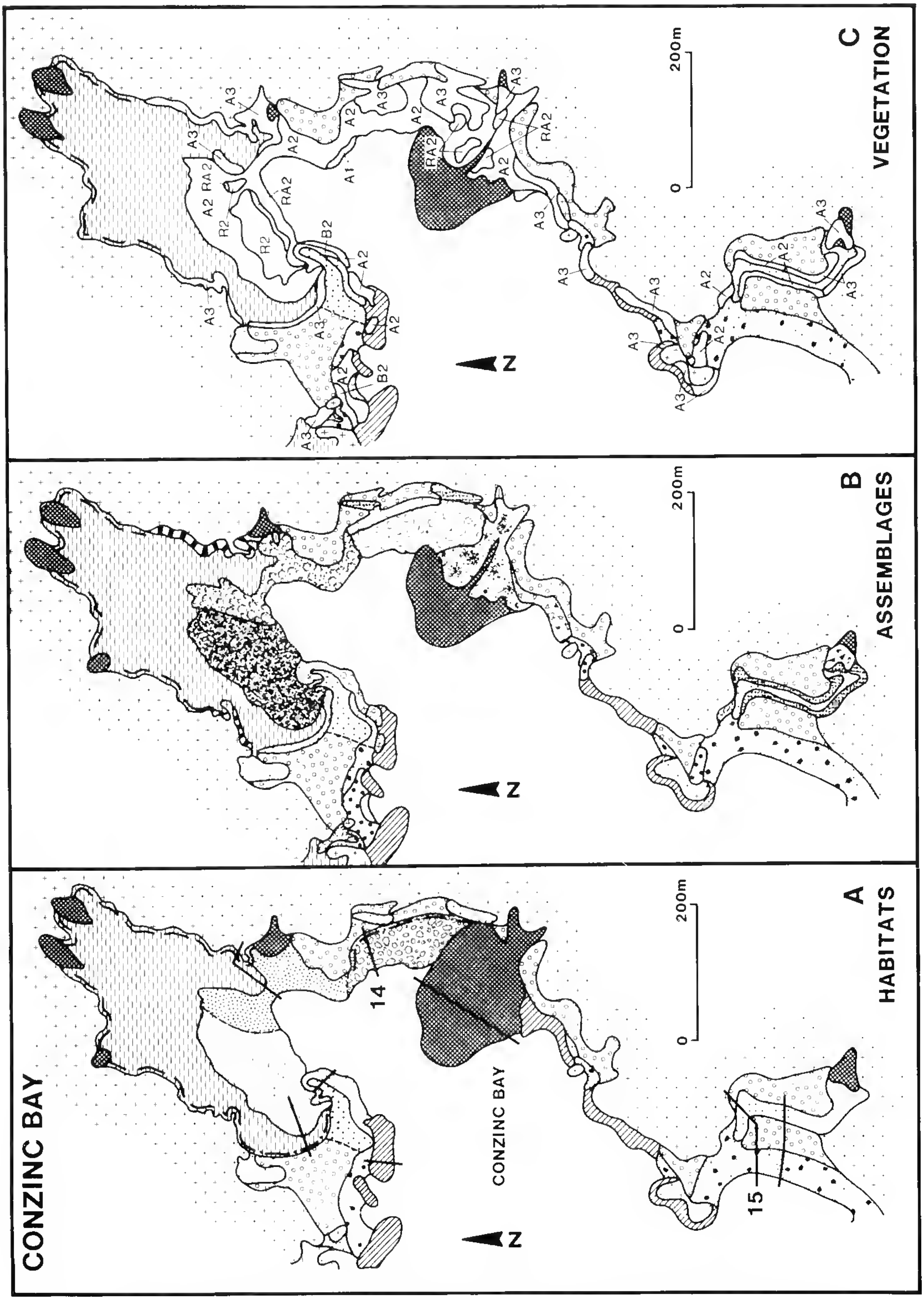


Figure 14.—Conzinc Bay. A. Habitat map. B. Vegetation assemblage map. C. Vegetation floristics and structure map.

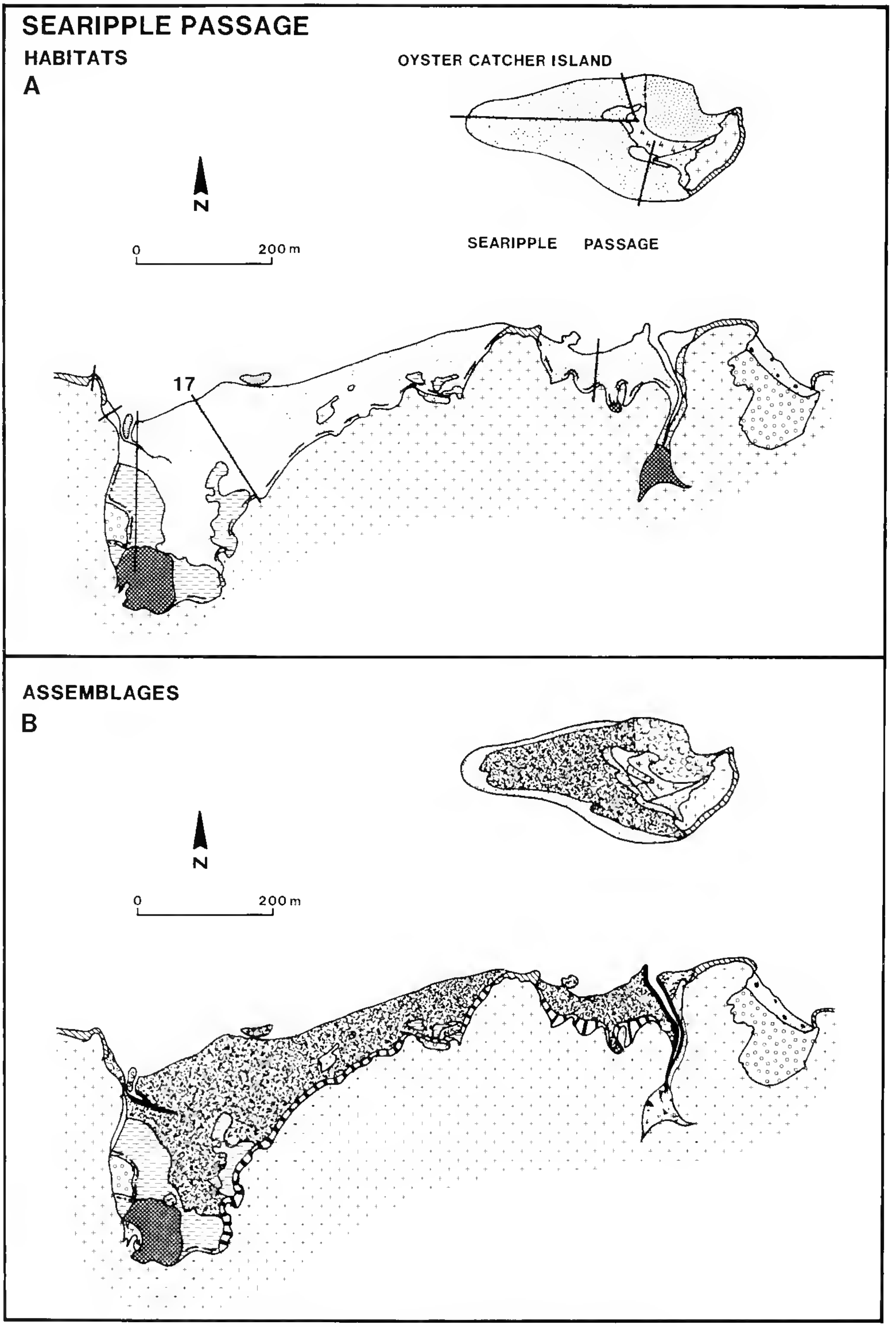


Figure 15.—Searipple Passage. A. Habitat map. B. Vegetation assemblage map.

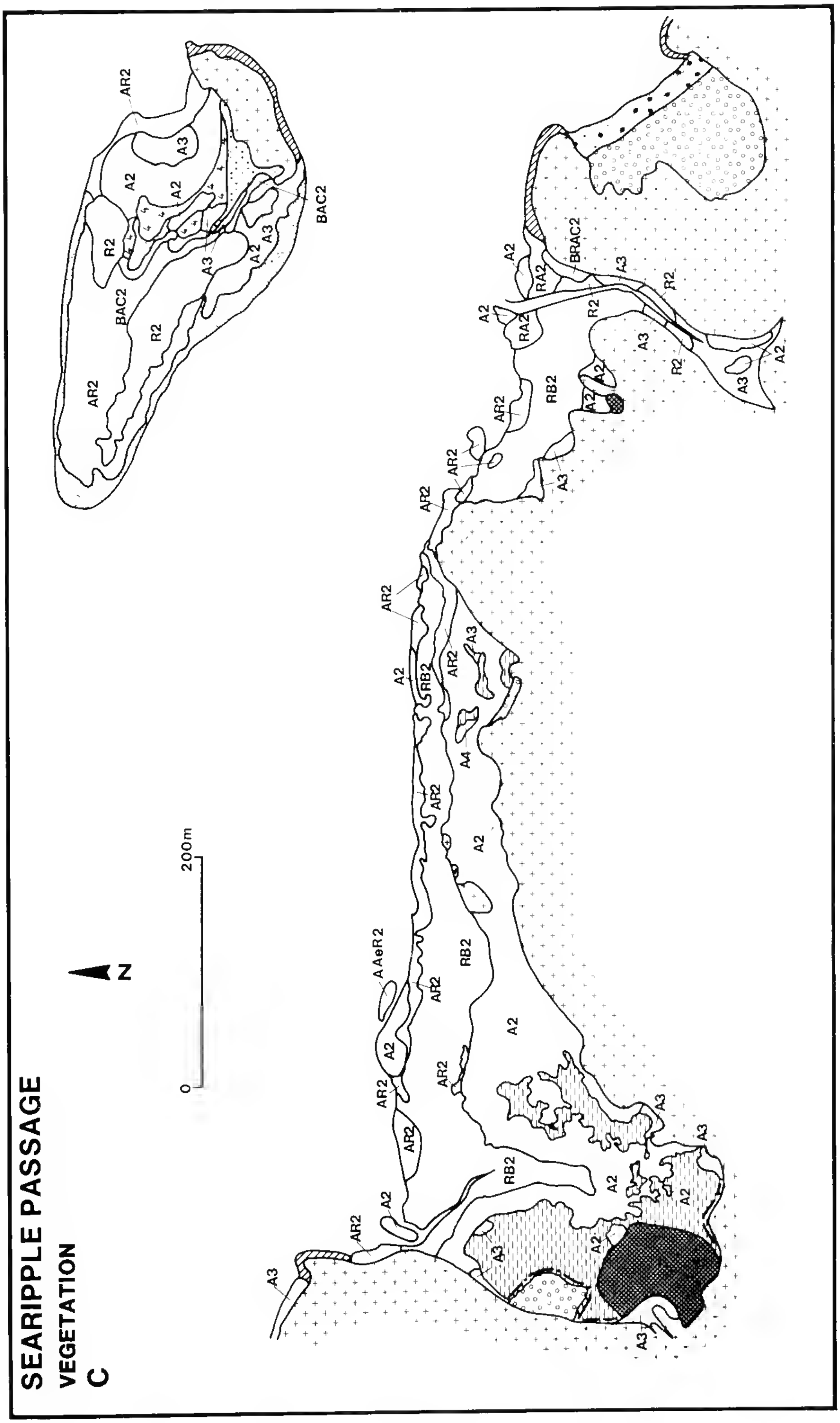


Figure 15.—Searipple Passage. C. Vegetation floristics and structure map.

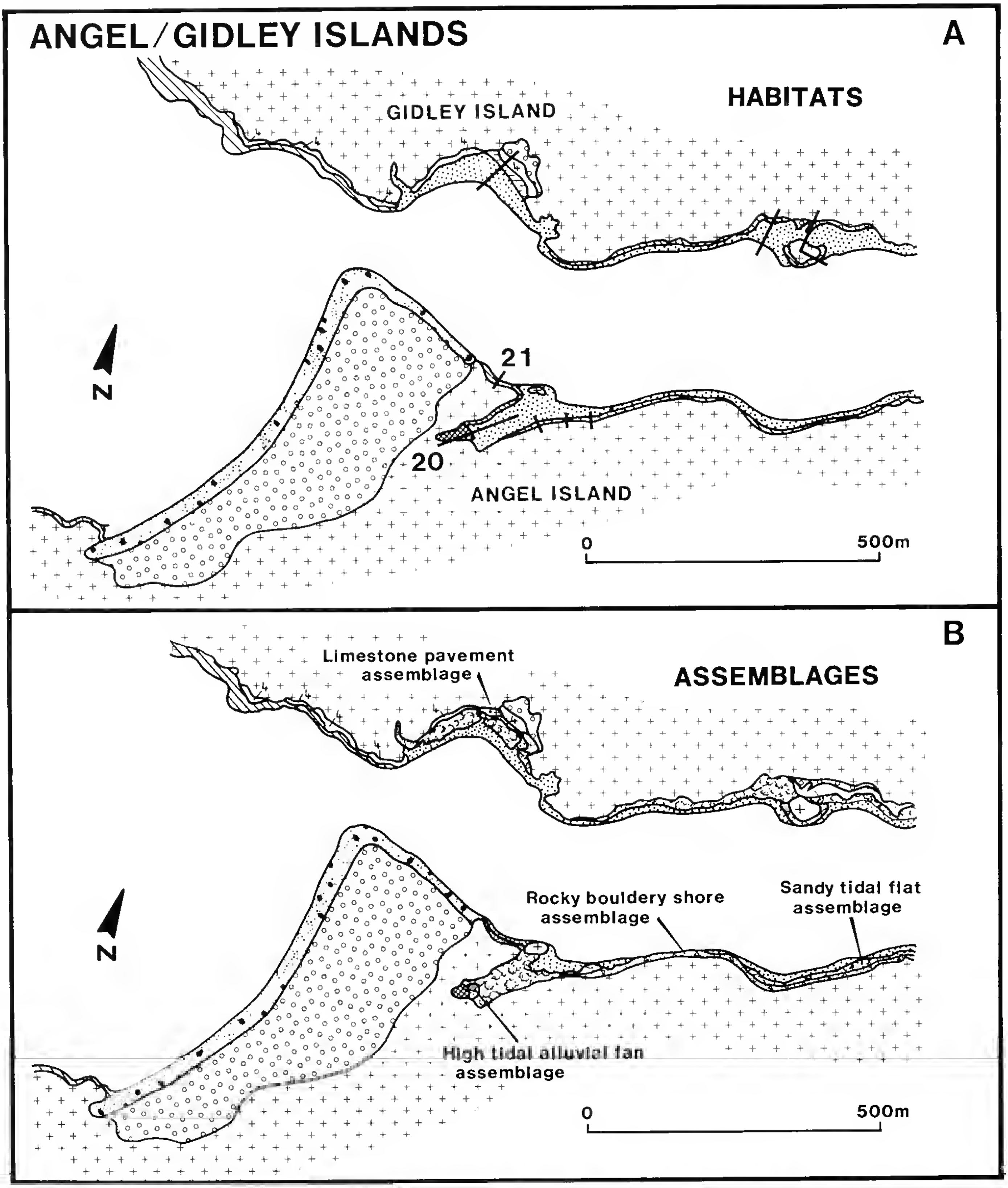


Figure 16.—Angel Island & Gidley Island: A. Habitat map. B. Vegetation assemblage map.

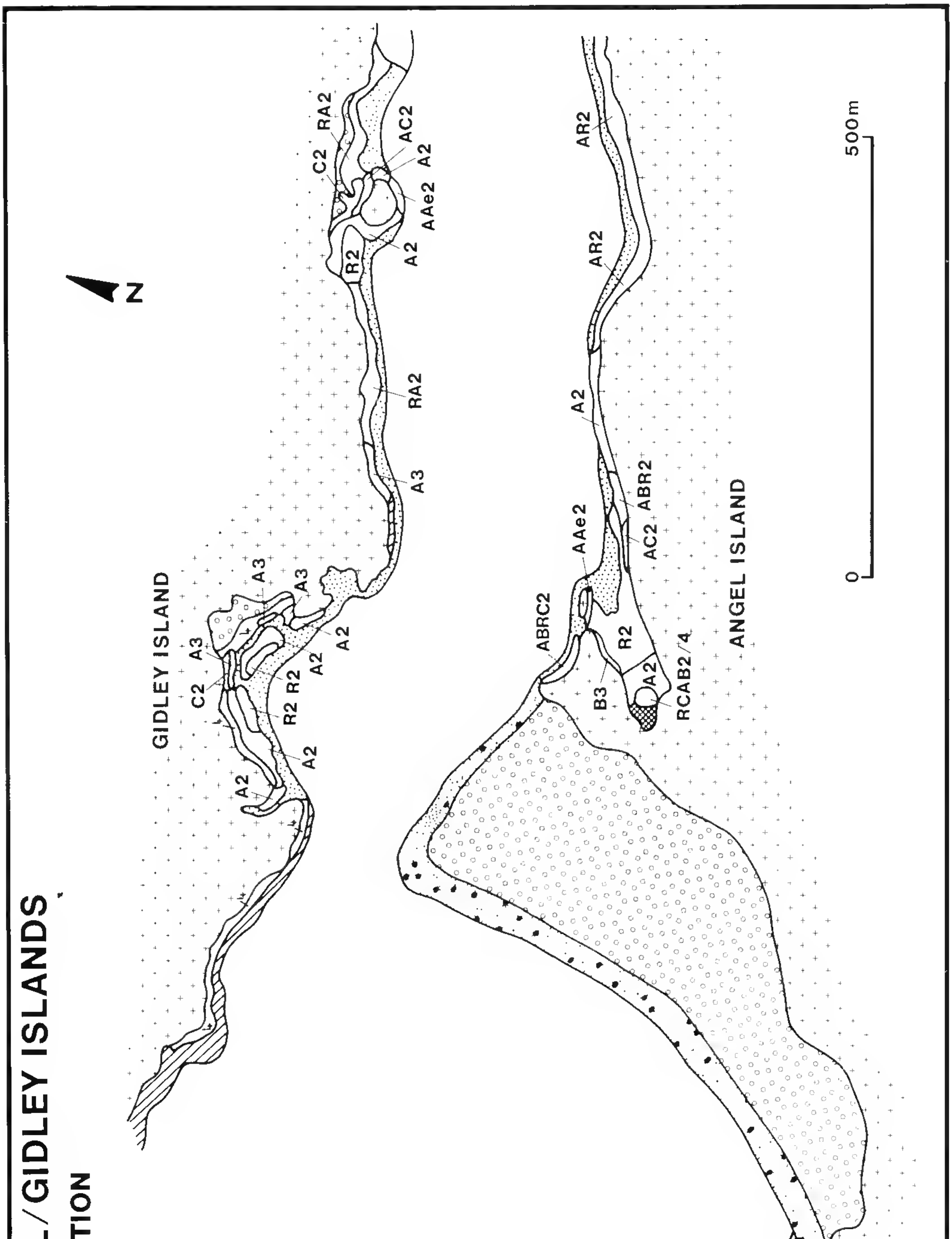


Figure 16.—Angel Island & Gidley Island: C. Vegetation floristics and structure map.

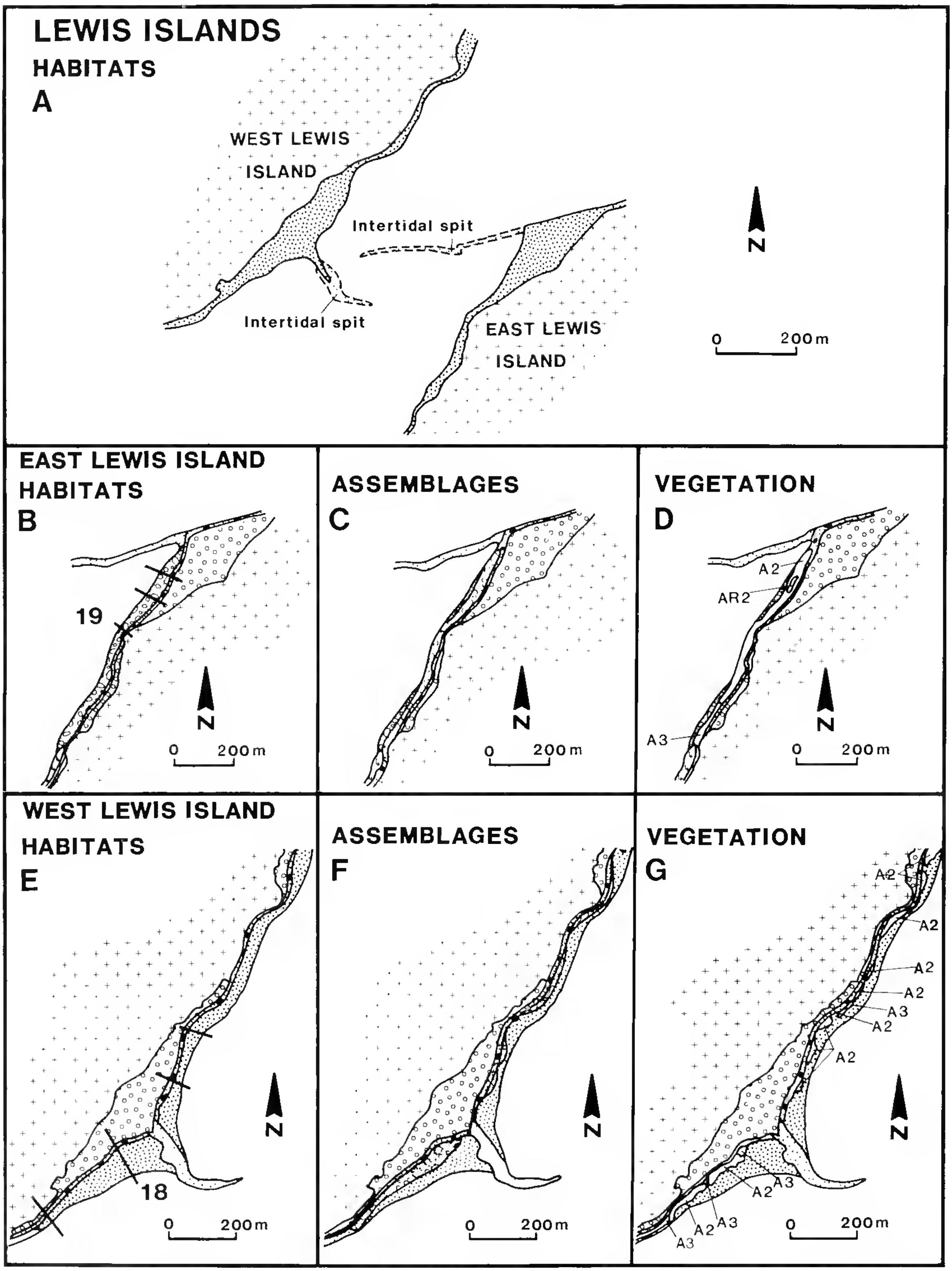


Figure 17.—Lewis Islands. A. Overview of habitats. B. East Lewis Island habitat map. C. East Lewis Island vegetation assemblage map. D. East Lewis Island vegetation floristics and structure map. E. West Lewis Island habitat map. F. West Lewis Island vegetation assemblage map. G. West Lewis Island vegetation floristics and structure map.

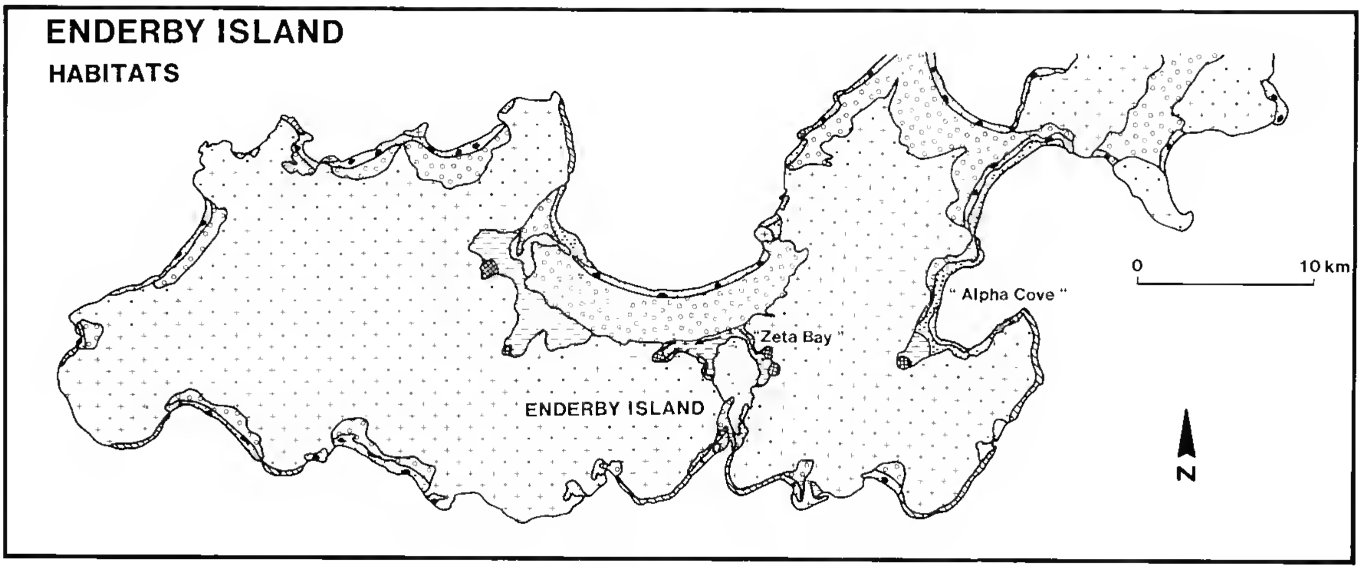


Figure 18.—An overview of habitats on Enderby Island.

2. Sandy tidal flat assemblage

Distribution: The sandy tidal flat assemblage inhabits the inclined surface of the main tidal sand sheet (Figs 12, 13, 14, 16, 17, 18 and 19). It also is a common and extensive unit. The formation is variable in width from *c.* 10 m up to 200-500 m, depending on the size of the embayment and the steepness of the shore where it occurs.

Main physico-chemical features and gradients within habitat: The sandy tidal flat is an inclined surface (*c.* 1:1 000) underlain by substrates of bioturbated root structured sand at *c.* MSL through to homogeneous/root-structured and laminated sand at MHWS. Much of the tidal water recharge is into burrows, root conduits and interstitial pore space such that excess water drains quickly and internal drainage is rapid. Bioturbation is important and results in the recycling of soils, soil aeration and groundwater recharge/mixing. Salinity of groundwater and soil water show gradients of *c.* 45‰ at MSL to *c.* 90‰ at MHWS. Frequency of flooding varies from twice daily at MSL to fortnightly at levels above MHWS.

Composition, zonation and structure of assemblage (Figs. 25, 26 and 28): The sandy tidal flat assemblage is a widely developed mangal in this area. It consists mainly of *Avicennia*, with very subordinant occurrence of *Rhizophora* and *Ceriops*. It is structurally zoned with distinctive structure types occurring at various levels across the tidal flat. The zonation and structure of the assemblage are:

(1) The most seaward zone at *c.* MSL is a forest (or closed scrub) of mature, recumbent and overmature *Avicennia*; the contact with the next zone is gradational;

(2) closed scrub of *Avicennia*; very scattered shrubs and saplings of *Rhizophora* may occur as an understorey component;

(3) closed *Avicennia* scrub grading landward to heath or shrubland;

(4) the salt flat.

3. Rocky-bouldery shore assemblage

Distribution: This assemblage inhabits the bouldery or rocky environments that form the headlands of embayments and occurs elsewhere intermittently along the extensive rocky shores of the archipelago islands (Figs. 12, 14, 16, 17, 18 and 19). The assemblage is regionally common since rocky shores are widespread. It is variable in width (less than 1m ranging up to 30 m) depending on slope, type of substrate and degree of exposure.

Main physico-chemical features and gradients within habitat: Bouldery, gravelly and fissured rock substrates are wave agitated and are veneered by a thin and patchy sediment cover. Internal drainage and seepage are rapid. Groundwater and soilwater where sampled show a gradient of salinity from *c.* 45‰ at MSL to *c.* 90‰ at HWS.

Composition, zonation and structure of assemblage (Figs. 24, 28 and 29): In most locations the rocky/bouldery shore assemblage is simply an open shrubland of *Avicennia*. However, in some rocky shore locations the assemblage contains a diverse aggregation of mangrove species. Where zonation is fully developed the assemblage is comprised of the following zones:—

(1) a seaward shrubland mainly of mature and overmature *Avicennia*;

(2) closed to open scrub of immature and mature *Rhizophora* and *Avicennia*;

(3) a landward open heath/shrubland of mixed *Avicennia* and *Ceriops* and rarely *Bruguiera*.

The density of mangroves is variable dependent on the exposure of the shore.

4. Spit and chenier fringe assemblage

Distribution: This assemblage inhabits the intertidal portions of sand spits and cheniers (Figs. 12, 13, 15, 20, 21 and 22). As such it is common but limited in area. The formation is usually only narrow *c.* 5-10 m wide. Its length is determined by the length of the spit on which it occurs; this is variable from 20 m to greater than 500 m.

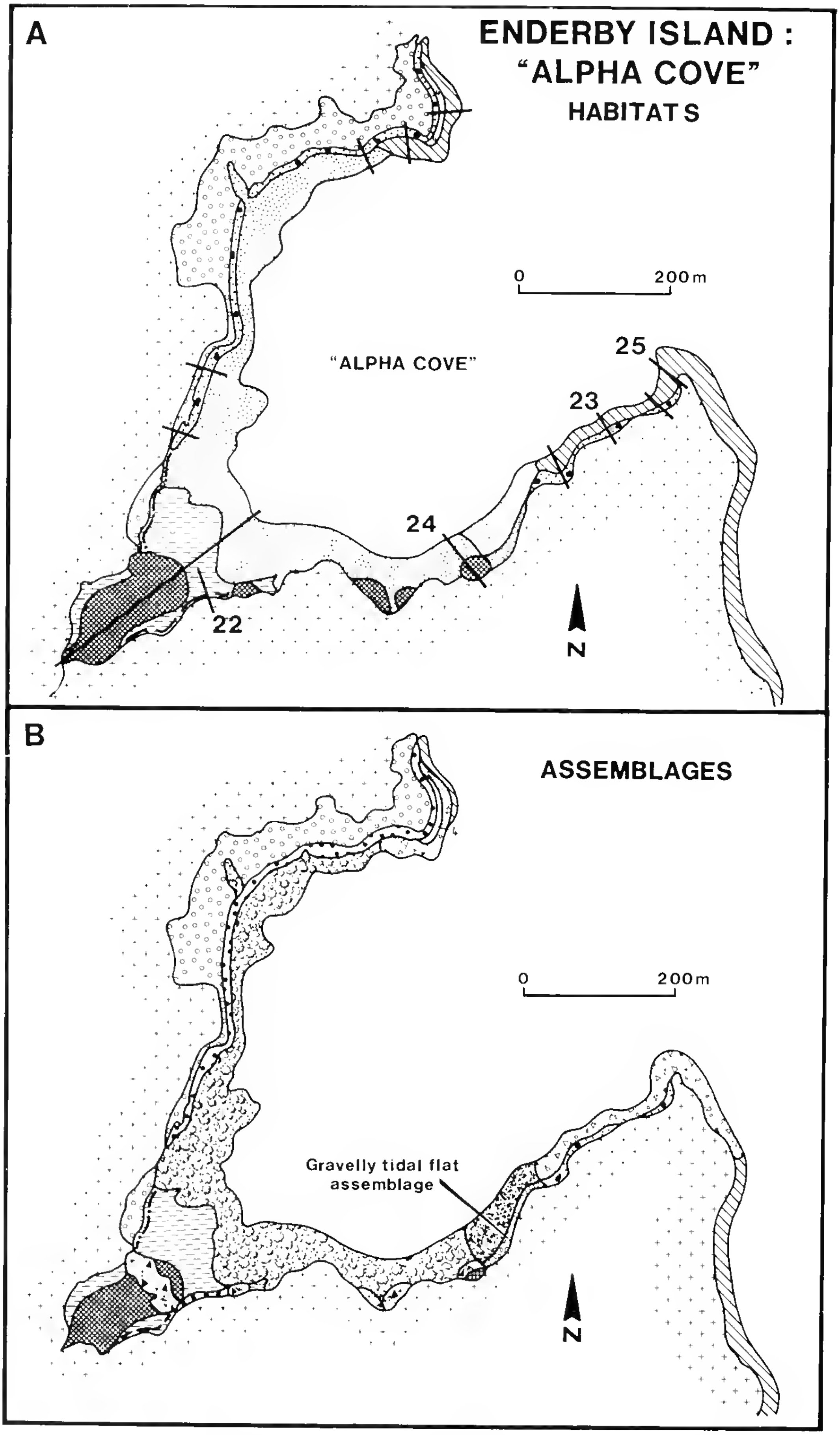


Figure 19.—Enderby Island, "Alpha Cove". A. Habitat map. B. Vegetation assemblage map.

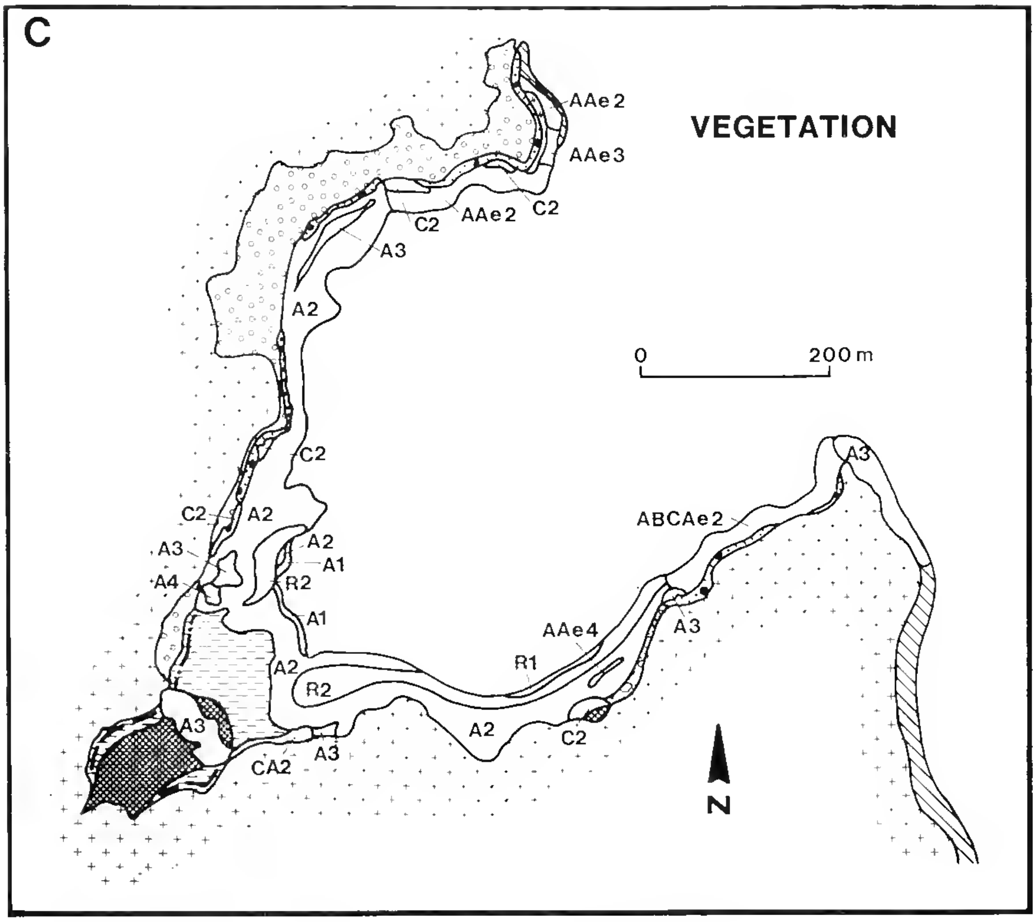


Figure 19.—Enderby Island, "Alpha Cove". C. Vegetation floristics and structure map.

Main physico-chemical features and gradients within habitats: The habitat where this assemblage occurs exhibits three types of gradients. The first is the inundation frequency. The sandy slopes of spits are inundated by tides twice daily at levels of HWN, fortnightly at HWS levels and are inundated by only storm water at supratidal levels. The second gradient involves substrates which vary from clean sands at landward parts of spit (and chenier) slopes, to mixed muddy sand/sand intercalations in transition zones, to sandy mud/muddy sand surfaces at seaward parts of slopes. Burrowing organisms mix the various layers of sediment at any given site. The third gradient is groundwater/soilwater salinity which varies from 40‰ at MSL to 60 or 70‰ at MHWS; thereafter depending on whether there is a freshwater lens under the crest of the spit or chenier, salinity may trend towards freshwater or to increasing hypersalinity.

Composition, zonation and structure of assemblage (Figs. 25, 26 and 30): The assemblage fringing a spit or chenier forms closed low forests and scrub at seaward parts, to open heath at high tide extremities. If fully developed on a relatively gently sloping shore, broadly four zones can be distinguishable:

(1) a seaward zone of *Avicennia* scrub;

(2) a zone between MHWN and MHWS of mixed species in which *Rhizophora*, *Avicennia* and *Bruguiera* are dominant forming closed low forest or scrub, with subordinant *Ceriops* and *Aegialitis*;

(3) a middle zone at *c*. MHWS of *Ceriops* and *Avicennia* forming scrub to tall heath with subordinate *Bruguiera*, *Aegialitis*;

(4) a landward zone above MHWS of *Avicennia* forming open to closed heath or shrubland.

Where the spit or chenier shore is steep, a zone of mixed *Ceriops*, *Bruguiera*, *Avicennia* and *Rhizophora* may develop.

5. Sandy beach assemblage

Distribution: The beach assemblage inhabits the steep surface of semi-exposed sandy beaches (Figs 12, 14, 18 and 19). As such it occurs in many locations throughout the region but is limited in area. The unit generally occurs as a narrow (*c*. 5-20 m wide) patch on the most sheltered portion of the beach.

Main physico-chemical features and gradients within habitat: As with the spit environment this habitat exhibits three types of gradients: (1) inundation frequency between levels of MSL and HWS (2) substrates, and (3) groundwater/soilwater salinity which varies from 40‰ at MSL to 60 or 70‰ at MHWS. Internal drainage within the habitat is rapid.

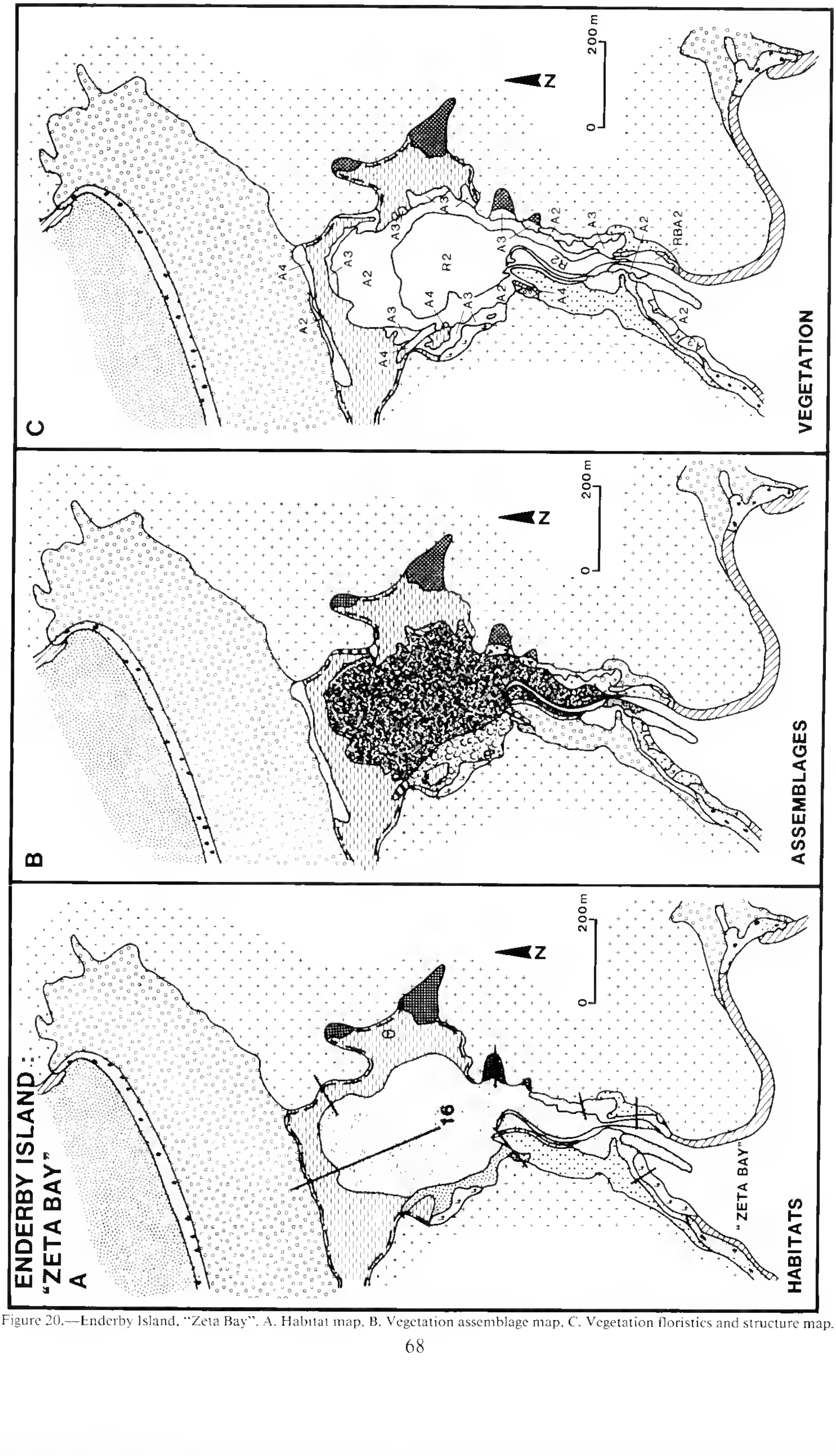


Figure 20.—Enderby Island, "Zeta Bay". A. Habitat map. B. Vegetation assemblage map. C. Vegetation floristics and structure map.

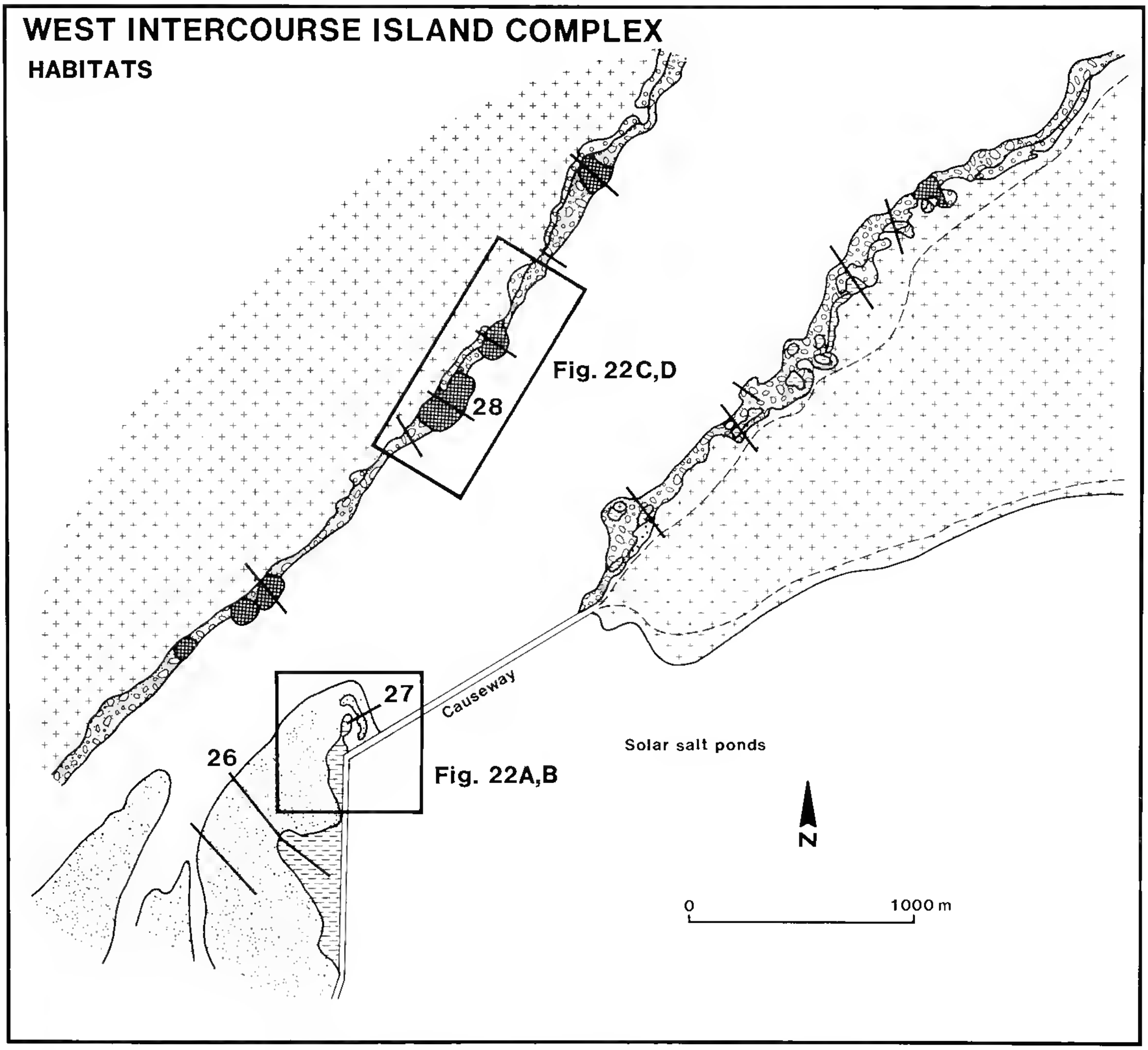


Figure 21.—West Intercourse Island Complex channel system habitat map overview.

Composition, zonation and structure of assemblage (Fig. 24): The beach assemblages form mixed scrub. Broadly, three zones are distinguishable:

(1) a seaward zone between MSL and MHWN of mixed species in which *Avicennia* is dominant, with subordinant *Rhizophora*, *Aegialitis* and *Aegiceras*;

(2) a middle zone at *c*. MHWN of *Rhizophora*, *Avicennia* with subordinate *Bruguiera*, *Ceriops*, *Aegialitis*;

(3) a landward zone above MHWS of *Avicennia* and *Ceriops*.

6. Hinterland fringe assemblage

Distribution: The hinterland fringe assemblage forms a discontinuous belt of mangrove vegetation along the edge of the hinterland (Figs 12, 14, 15, 18, 19 and 20). The unit is very narrow (usually 2 m-5 m wide), but may be developed along a substantial length of the hinterland margin. Its continuity is disrupted by either alluvial fans, or spits, or patches of extreme hypersalinity of groundwater/soilwater.

Main physico-chemical features and gradients within habitat: The hinterland fringe assemblage inhabits the tidal flat/hinterland contact. The habitat is distant from any prevailing marine processes such as frequent tidal inundation and there is no gradient of inundation-frequency that is relevant. The main two gradients within the habitat are salinity and substrates. The groundwater and soilwater show a gradient of salinity from hypersaline at landward (usually 70-90°/oo) to extreme hypersaline at seaward (in excess of 100°/oo). Additionally, the substrate grades from being predominantly gravel and muddy sand/gravel to being more sand and mud dominated to seaward. Mangrove physiognomic/structural zonation within the assemblage virtually parallels these gradients. Crab bioturbation is a common process that results in soil turnover, aeration and groundwater/soilwater mixing.

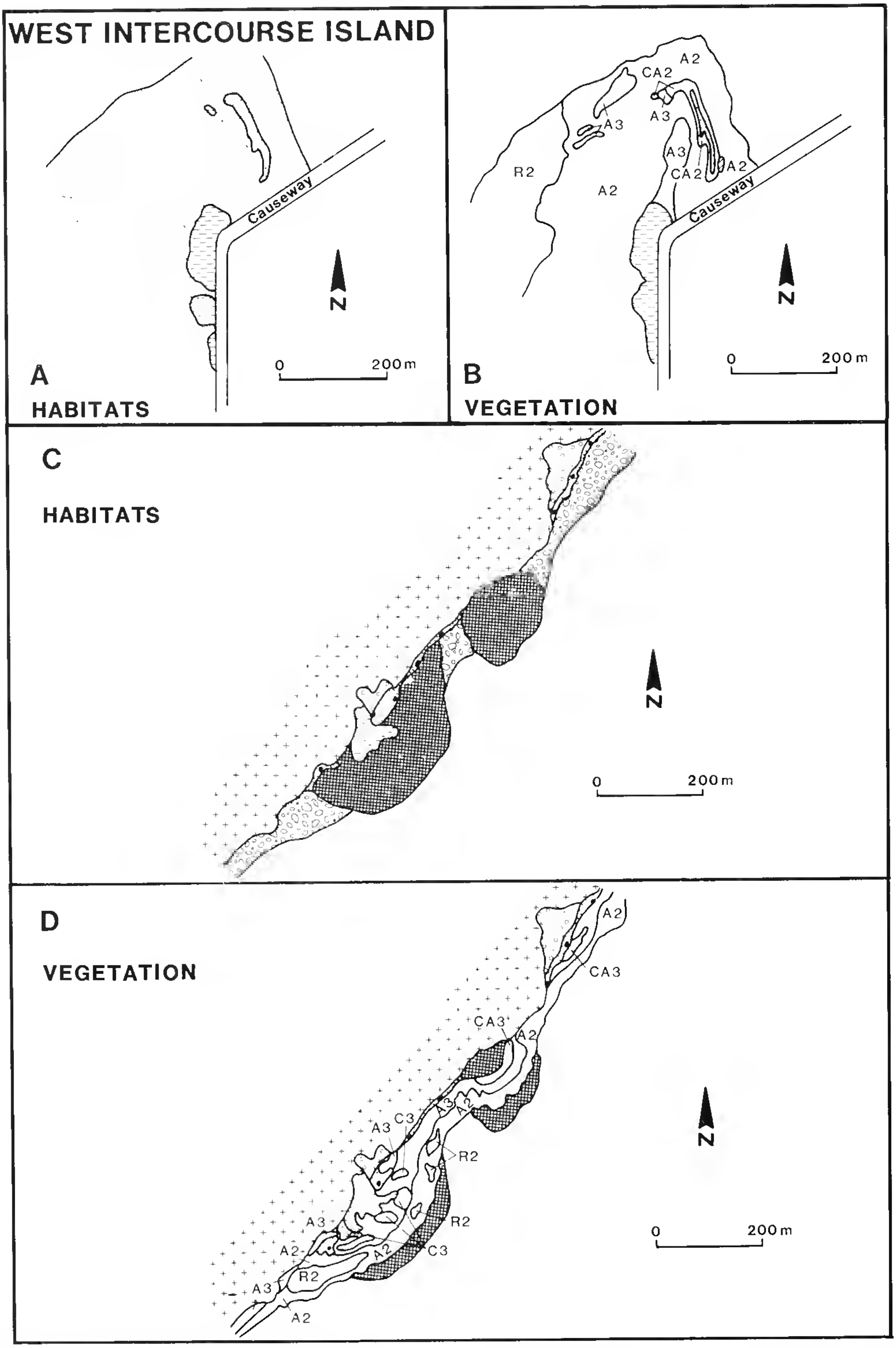


Figure 22.—West Intercourse Island. A. Connective tidal land habitats. B. Connective tidal land vegetation floristics and structure. C. Channel shore habitats. D. Channel shore vegetation structure and floristics.

Composition, zonation and structure of assemblage (Figs. 24, 25 and 27): The mangrove of the hinterland fringe assemblage forms a shrubland to closed scrub to open heath of *Avicennia*.

7. Gravelly tidal flat assemblage

Distribution: The gravel flat assemblage inhabits the inclined surface of a tidal sheet of gravel/sandy gravel (Figs. 12, 14 and 17). It is an areally limited and intermittently distributed unit. Generally the formation is narrow, *c.* 50 m wide, but may be up to 200 m wide.

Main physico-chemical features and gradients within habitat: The habitat is developed as a gently inclined surface (*c.* 1:1 000) of gravel/sandy gravel. Much of the substrate is composed of gravel with variable interstitial sand. Tidal flooding varies from twice daily at MSL to fortnightly at NHWS. Fauna is not abundant but bioturbation by crabs and other benthos effect soil turnover in interstitial spaces between gravel particles. Groundwater/soilwater salinity is *c.* 40‰ at MSL grading up to *c.* 70-90‰ at HWS. Much of the tidal water recharge is through the interstitial pore space such that excess water drains rapidly. Internal drainage is rapid and consequently there is efficient recharge and discharge of groundwater.

Composition, zonation and structure of assemblage (Fig. 27): This assemblage has simple composition and structure with little tendency toward zonation. However, when developed, zonation is as follows:

(1) to seaward there is a closed low forest to scrub of *Avicennia*, followed to landward by
(2) closed scrub of *Avicennia* with a scattered understorey of *Rhizophora* shrubs and saplings, followed by
(3) closed scrub of *Avicennia* with localised patches of salt flat.

8. High tidal alluvial fan assemblage

Distribution: High-tidal alluvial fan assemblage inhabits the high-tidal to supratidal alluvial fans (Figs. 12, 13, 14, 15, 16, 18, 19 and 20). The assemblage is common but scattered in small patches corresponding to sites where terrestrial drainage intersects the tidal flats. The extent of the unit is determined by the size of the habitat; usually the assemblage covers an area some 100 m or less across.

Main physico-chemical features and gradients within habitat: The habitat is generally fan or deltoid in shape and is underlain by gravelly and sandy substrates interlayered with muddy layers and cemented by calcrete sheets. Freshwater seeps into the habitat and maintains a gradient of groundwater/soilwater salinity which varies from 60‰ at extreme landward sites to *c.* 90‰ and greater at seaward sites.

Composition, zonation and structure of assemblage (Figs 25, 26, 28 and 29): The high tidal alluvial fan assemblage contains 2 species of mangrove: *Avicennia* and *Ceriops*. There is compositional and structural zonation in response to salinity gradients:

(1) a landward zone of *Avicennia* forming closed to open heath where there is marked freshwater seepage;
(2) a middle zone of *Avicennia* and *Ceriops* and rare *Bruguiera* forming closed to open heath to scrub;
(3) a seaward zone mostly of closed to open heath of *Avicennia* which may grade into, or abruptly join, the salt flat.

Where there is limited freshwater influx the assemblage may consist of *Avicennia* open shrubland.

9. Mid-tidal alluvial fan assemblage

Distribution: The mid-tidal alluvial fan assemblage inhabits the gravelly fan-shaped alluvial deposits that debouch onto the mid-tidal flat (Figs 13, 14, 21 and 22). As such it is an areally limited and intermittently distributed unit. Generally the formation is *c.* 300 m across the fan.

Main physio-chemical features and gradients within habitat: The habitat is developed mainly at MSL-HWN and accordingly there is little development of gradients. The surface of the habitat is comprised of gravel. Groundwater/soilwater is *c.* 40‰ at MSL grading up to 55‰ at HWN. Internal drainage is rapid. Bioturbation by crabs and other fauna effect soil turnover in interstitial spaces between gravel components.

Composition, zonation and structure of assemblage (Fig. 30): This assemblage has simple composition and structure with little tendency toward zonation. However, three compositional/structural extremes are evident in the assemblage:

(1) closed low forest to scrub of *Avicennia*;
(2) closed scrub of *Avicennia* with a scattered understorey of *Rhizophora* shrubs and saplings;
(3) closed scrub of *Avicennia* and less common *Rhizophora*.

10. Tidal creek assemblage

Distribution: This assemblage inhabits the banks of tidal creeks (Figs 12, 15 and 20). As such it is a relatively common, but generally narrow unit only *c.* 5-10 m wide; its length, as determined by the length of the creek habitat, may be up to 500 m long.

Main physico-chemical features and gradients within habitat: The creek banks are underlain by a substrate of bioturbated mud which grades from thixotropic and root-structured at *c.* MSL, to plastic, root-structured and burrow-structured at *c.* HWN. The surface is steep or cliffed at the creek bank edge, and adjoining slopes are relatively more steeply inclined (1:100-1:50) than the main tidal flat. Much of the tidal water recharge is through burrows and root conduits. Internal drainage and run off are relatively more rapid than the main tidal flat. Groundwater and soilwater salinities for wide, deep creeks, vary from *c.* 40‰ at MSL to *c.* 50‰ at (landward) parts of the habitat where it grades upslope and laterally into the main tidal flat, and *c.* 80-90‰ at headwater extremities at levels of *c.* MHWS. Frequency of flooding is twice daily for several hours at the creek-bank channel edge, and for several hours per week at the headwater extremes of the habitat.

Composition, zonation and structure of assemblage (Fig. 24): The tidal creek assemblage is composed of *Avicennia* and *Rhizophora* and the assemblage is not zoned. The assemblage consists of either of these two components:

(1) mainly *Rhizophora* with very scattered *Avicennia*; these inhabit and overhang steep banks and form closed low forests, or

(2) *Rhizophora* and *Avicennia* in approximately equal proportions forming closed low forests.

Frequently, the only difference between the creek bank assemblage and the adjacent tidal flat assemblage is an increase in the height and luxuriance of *Avicennia* and *Rhizophora*. As such the creek bank assemblage is generally structurally distinct from the adjacent tidal flat.

11. High tidal dune margin assemblage

Distribution: This assemblage inhabits the narrow zone of contact where a muddy tidal salt flat adjoins a dune terrain (Figs 13, 14, 16, 19 and 20). The assemblage itself is narrow, 5-10 m wide, and its length is determined by the extent of the interface between the geomorphic units.

Main physico-chemical features and gradients within habitat: There is a minor slope gradient since the habitat is characterised by a slightly steeper slope than the adjoining tidal flat. In addition there may be a gradient in substrate properties with more sandy substrates occurring to landward. Within the habitat there also is a narrow gradient in groundwater and soilwater salinity since the hypersalinity of the adjoining salt flat is diluted by seepage of fresh water or oceanic water from the toe of the dunes. The salinity is *c.* 50-70‰ within the habitat, and grades abruptly to 90-100‰ at the contact with the adjoining salt flat. Crabs and other burrowing biota are important benthic faunal components of this habitat.

Composition, zonation and structure of assemblage (Figs 26 and 27): The dune margin assemblage generally consists of a simple *Avicennia* shrubland or scrub. However in some localities where there is marked freshwater or seawater seepage there is a zonation of mangrove from landward to seaward:

(1) *Avicennia* low open heath;

(2) mixed assemblage of *Avicennia* and *Ceriops* closed heath to scrub with less common *Bruguiera* and *Aegialitis*;

(3) *Avicennia* low closed heath to scrub.

12. High-tidal lagoon assemblage

Distribution: This assemblage occurs where a beach ridge or dune has impounded a depression or a tidal creek which has cut through a dune terrain (Figs 14 and 18). The assemblage occurs along the lagoon margins. As such the assemblage is restricted in distribution. The unit is very narrow fringe usually 1-4 shrubs wide along the edge of lagoons, and may be developed along some lagoons for up to 300 m.

Main physico-chemical gradients with habitat: This habitat is situated mainly at HWS and receives tidal recharge fortnightly; its substrates are relatively homogeneous and sandy. Accordingly, the main gradient within the habitat is salinity and depth of waterlogging. The soilwater/groundwater salinity varies from hypersaline (*c.* 50-90‰) along lagoon margins, where seepage from adjacent sand bodies occurs, to excessively hypersaline along lagoon centres. The depth of the waterlogging varies from less than 1m depth along lagoon banks to greater than 1m depth in the centre.

Composition, zonation and structure of assemblage (Fig. 27): The assemblage is composed only of one species, *Avicennia marina*, which forms an open scrub or shrubland.

13. Shoal assemblage

Distribution: The shoal assemblage occurs on localised shoal build-ups within creek channels and creek mouths (Figs. 12, 15 and 20). However, since not all creeks have appropriate shoals, the distribution of this assemblage is limited and patchy. The unit is usually limited in area extent and covers shoals *c.* 10-20 m across the width.

Main physico-chemical features and gradients within habitat: The shoal habitat is fairly consistent in its internal physico-chemical environment with little tendency for differentiation into internal gradients. The habitat is underlain by thixotropic mud, or muddy sand or sand with salinity of *c.* 40‰. The only gradient is a relatively minor one of frequency of inundation, but even so the bulk of the shoals are inundated daily for several hours with each tidal flooding. The slopes of shoals are variable ranging from hummocky and flat-topped types where they occur in tidal creek areas, to steeply-inclined surfaces where they are plastered on the low parts of the cliffed creek banks.

Composition, zonation and structure (Fig. 24): This assemblage has simple structure with little tendency toward zonation. However, three structural/compositional extremes are evident in the assemblage:

(1) closed heath to scrub dominated by *Aegiceras*;

(2) open heaths of *Aegialitis*;

(3) closed/open heath of *Aegiceras* with an understorey of *Aegialitis*.

Avicennia seedlings, saplings and small shrubs form a local minor part of this assemblage.

14. Limestone pavement assemblage

Distribution: This assemblage inhabits limestone pavements and associated limestone slab/boulder sheets (Figs. 13, 15, 16, 19 and 20) but it is not a widespread unit. Generally the formation is limited in both its area extent and width (less than 15 m wide).

Main physico-chemical features and gradients within habitat: The habitat is wave agitated and generally swept clean of sand and muddy sediment. Large slabs and boulders may be strewn on the surface and locally there may be fissured and cliffed limestone. The main gradient evident is frequency of inundation; tidal waters flood the habitat twice daily at MSL and fortnightly at MHWS. Boring and burrowing fauna (such as crabs, gobioid fish, octopus) inhabit cavities and excavations in the limestone but these appear to have little influence on mangrove populations. Groundwater was too difficult to sample in limestone so that information on this factor is lacking, and soilwater was not sampled because of the paucity of soil.

Compositon, zonation and structure of assemblage (Fig. 26): In most locations the limestone pavement assemblage is an open shrubland of *Avicennia* developed in small groves or patches.

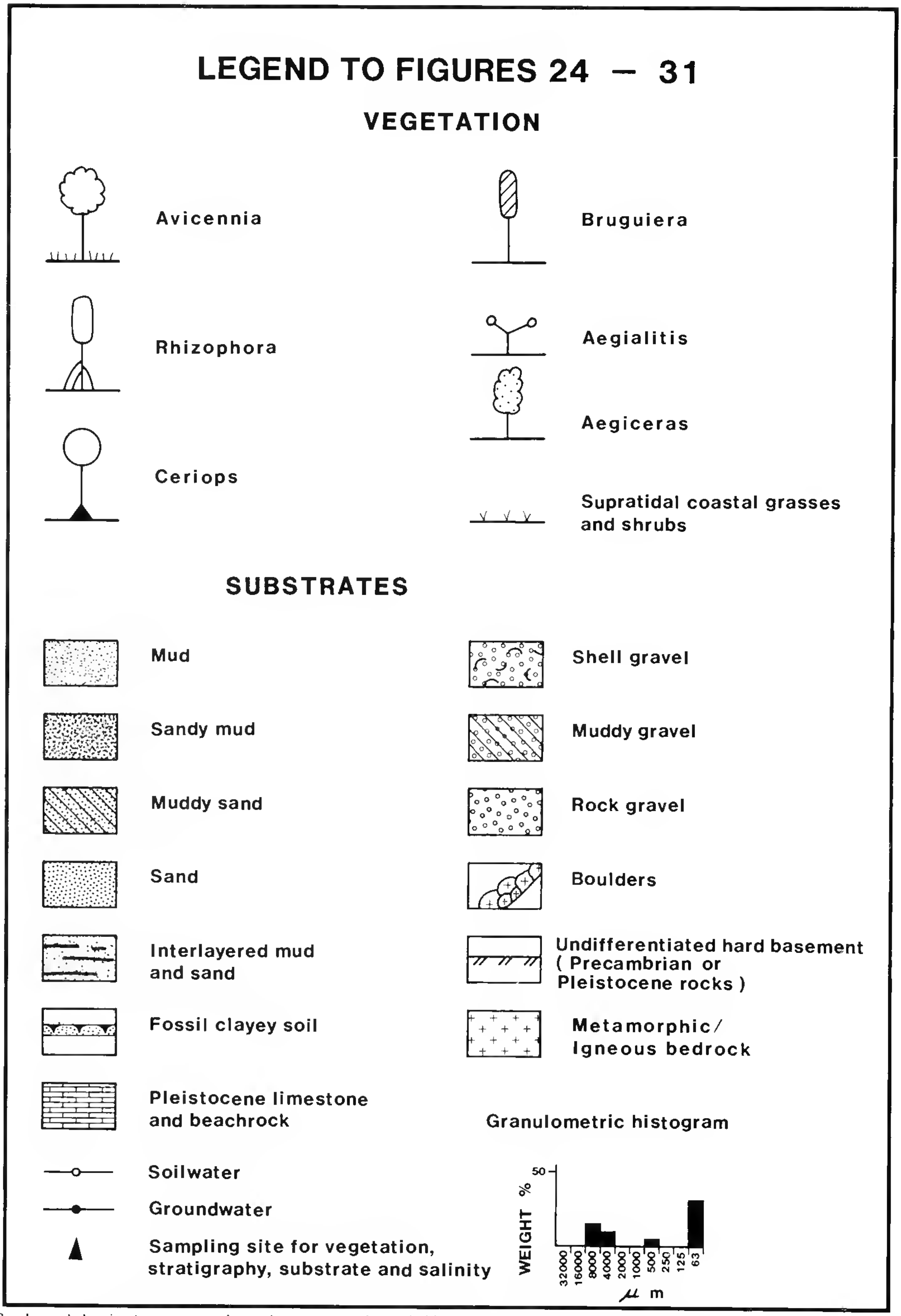


Figure 23.—Legend showing key to vegetation, substrates, granulometric histogram and other sampling information pertaining to transect cross-sections presented in Figures 24 to 31. The location of transects is shown on the maps presented in Figures 12 to 22. See also Figure 3 for additional information on style of data presentation.

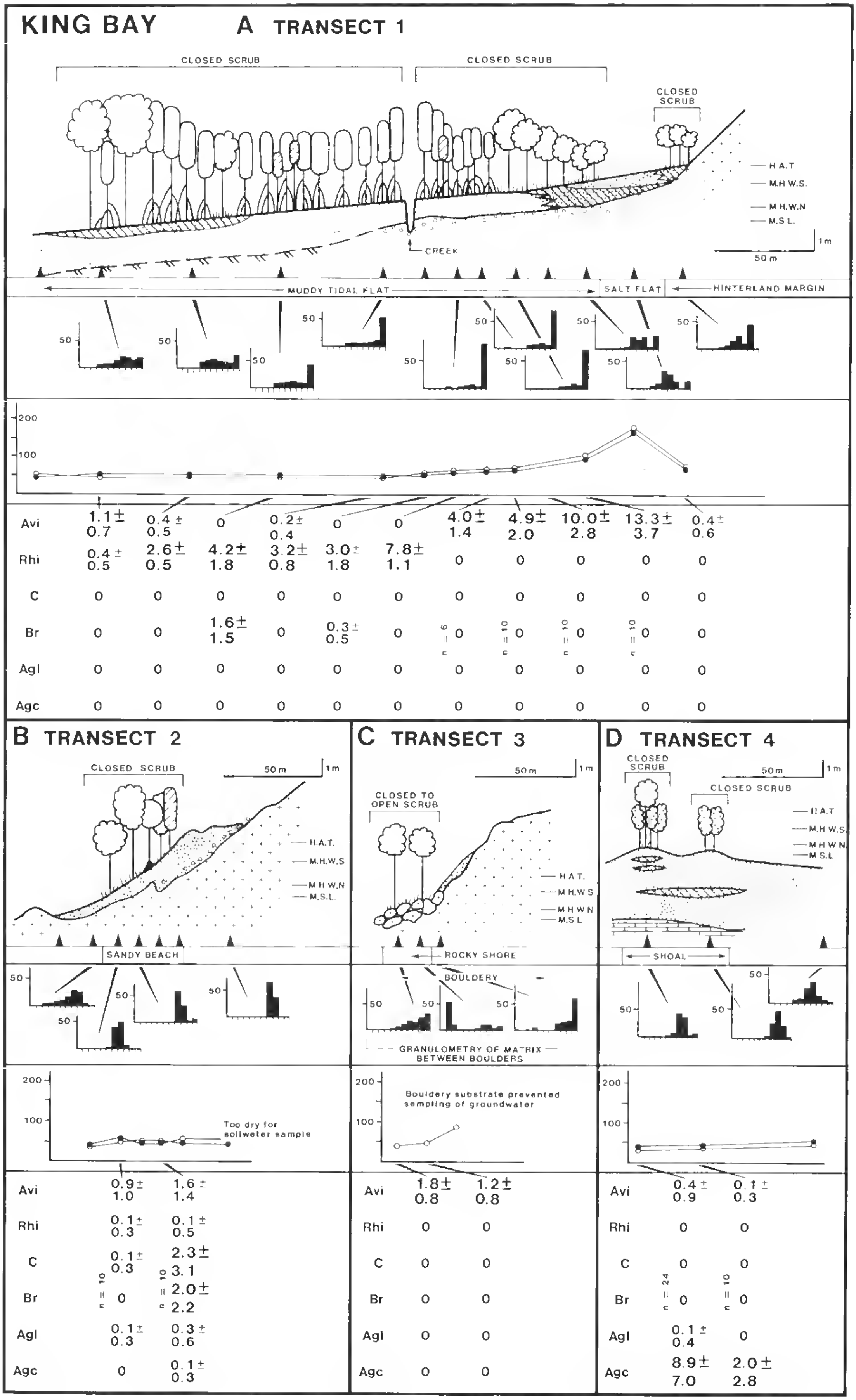


Figure 24.—Profiles showing the information obtained from field surveys. A. Transect 1. King Bay. B. Transect 2. King Bay. C. Transect 3. King Bay. D. Transect 4. King Bay.

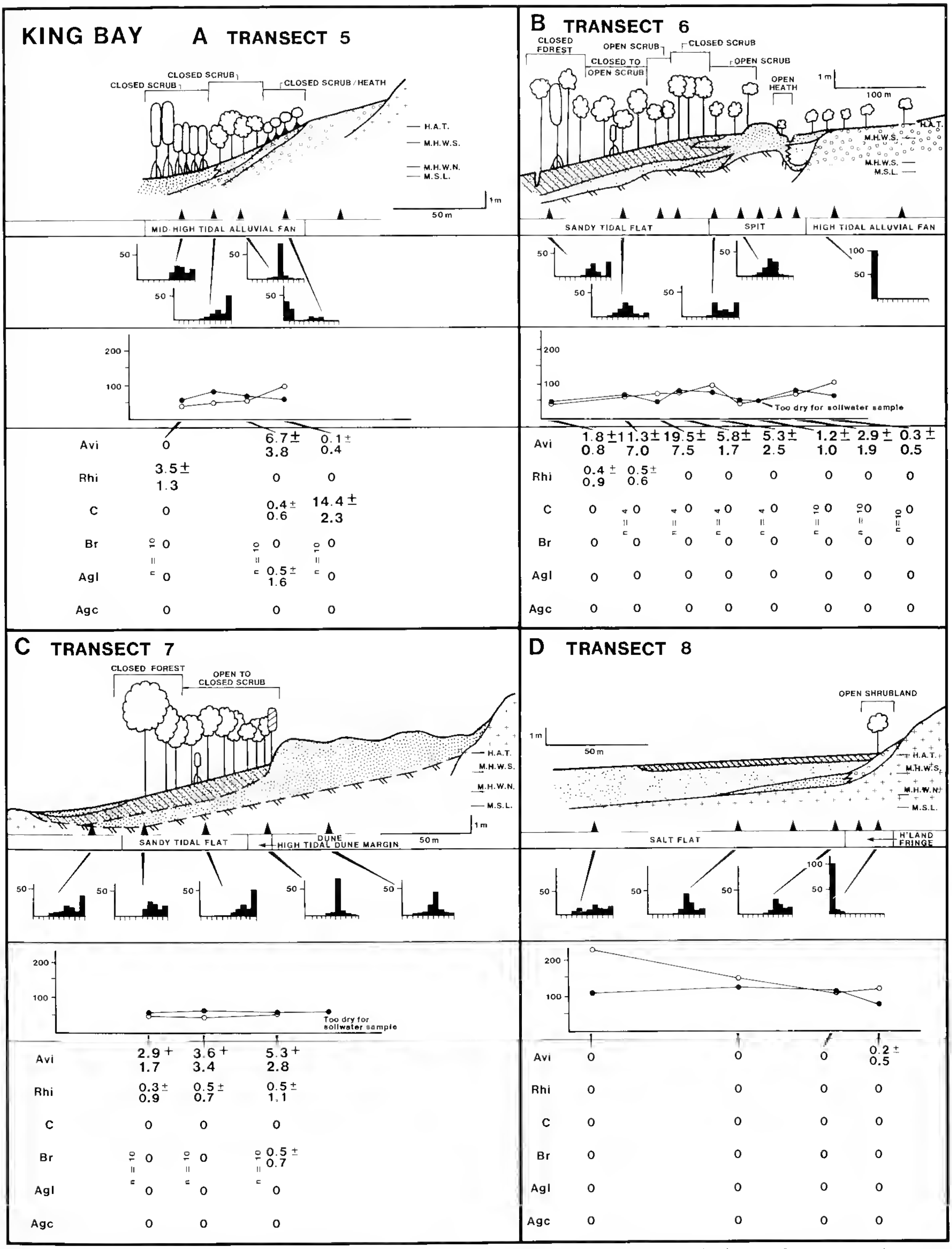


Figure 25.—Profiles showing the information obtained from field surveys. A, Transect 5, King Bay. B. Transect 6, King Bay. C, Transect 7, King Bay. D, Transect 8, King Bay.

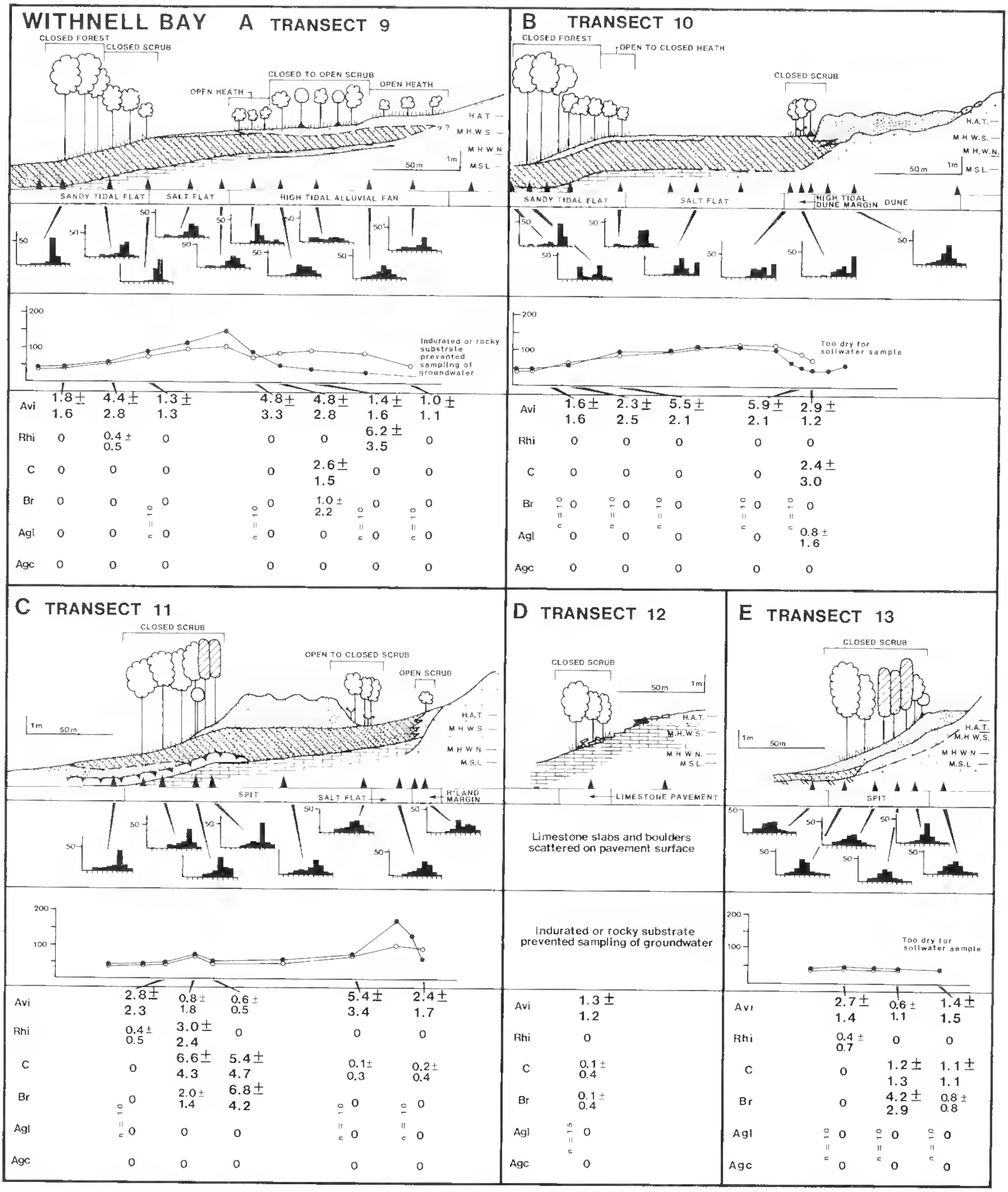


Figure 26.—Profiles showing the information obtained from field surveys. A. Transect 9, Withnell Bay. B. Transect 10, Withnell Bay. C. Transect 11, Withnell Bay. D. Transect 12, Withnell Bay. E. Transect 13, Withnell Bay.

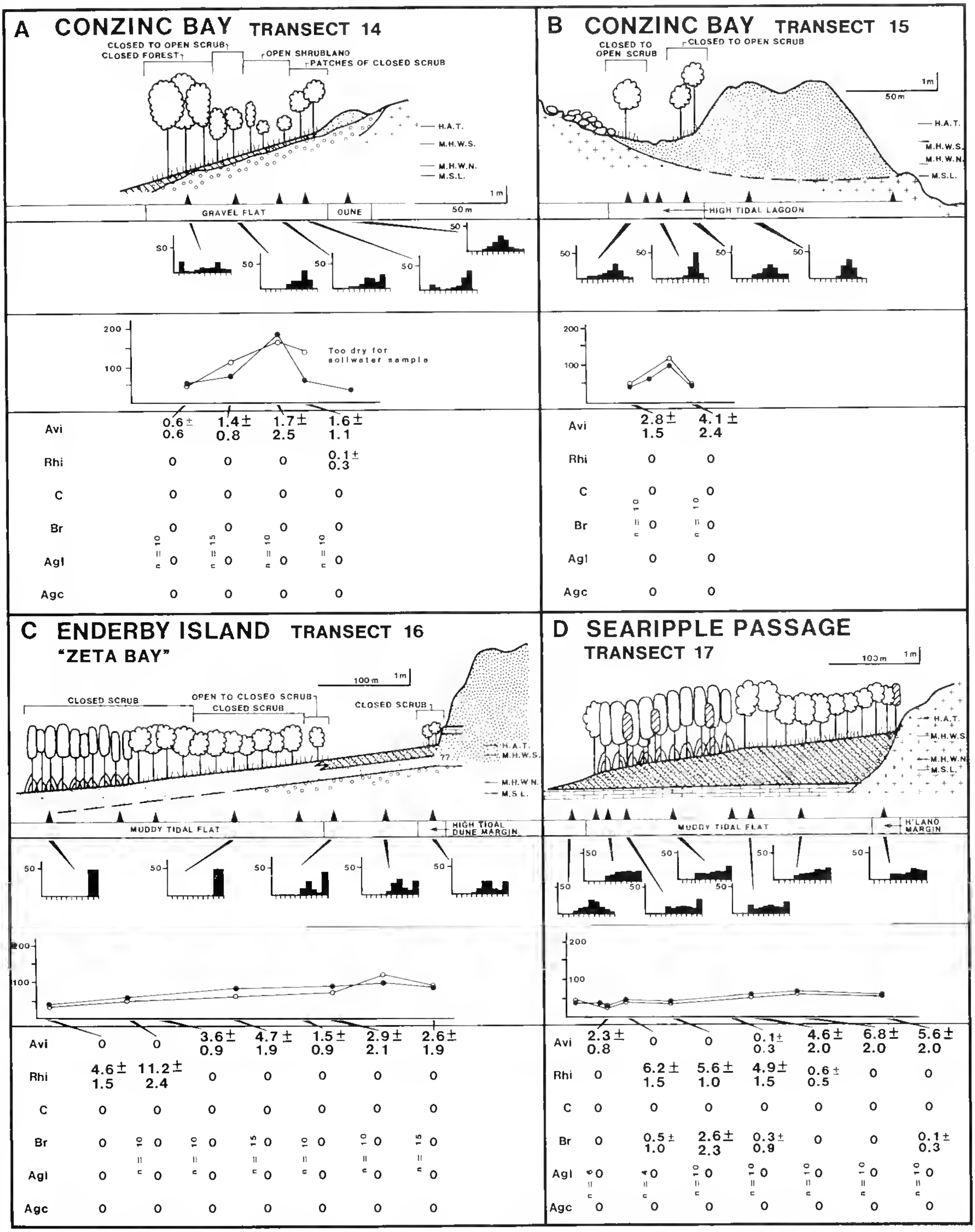


Figure 27.—Profiles showing the information obtained from field surveys. A, Transect 14, Conzinc Bay. B, Transect 15, Conzinc Bay. C, Transect 16, Zeta Bay, Enderby Island. D, Transect 17, Searipple Passage.

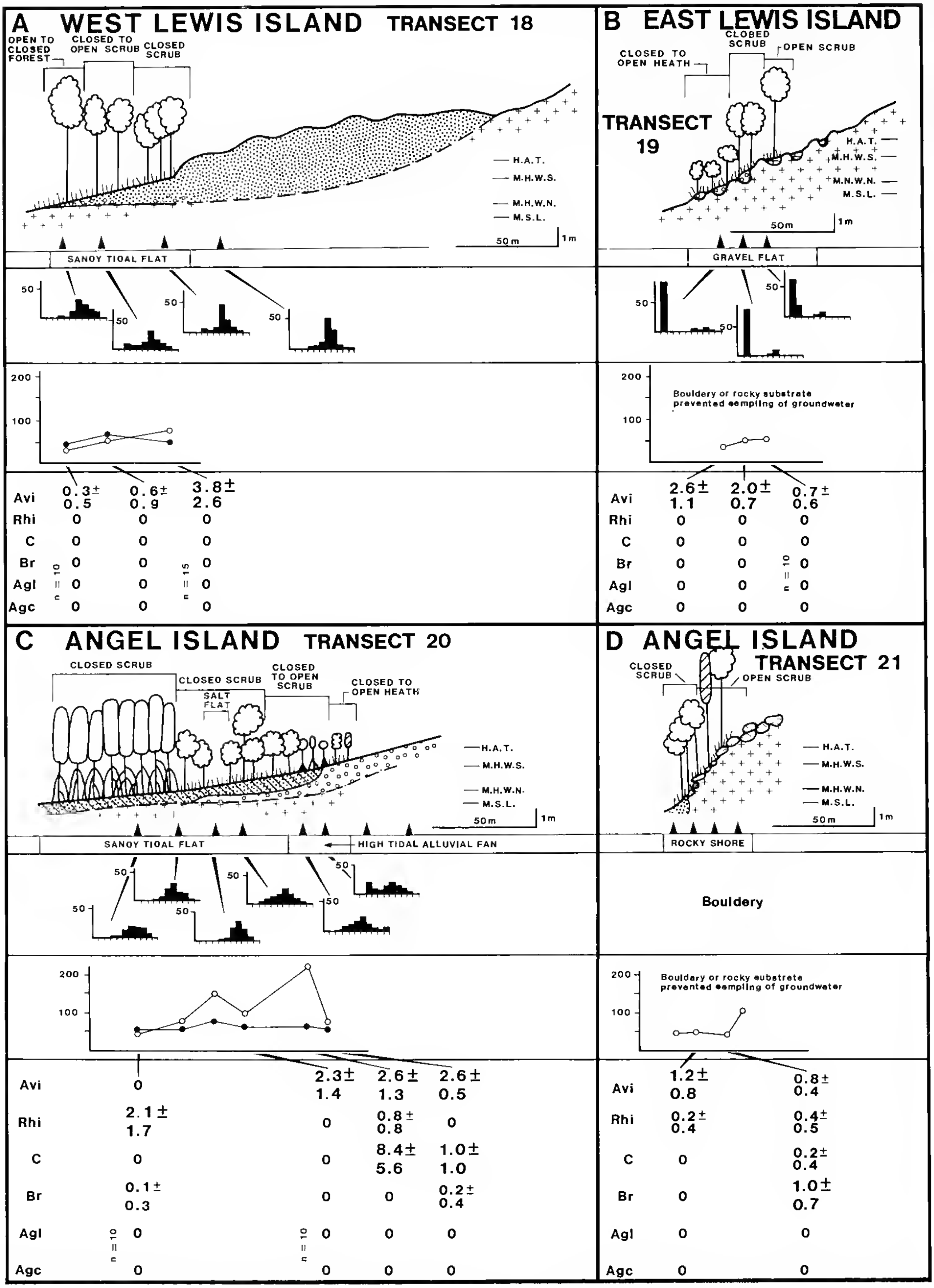


Figure 28.—Profiles showing the information obtained from field surveys. A, Transect 18, West Lewis Island. B, Transect 19, East Lewis Island. C, Transect 20, Angel Island. D, Transect 21, Angel Island.

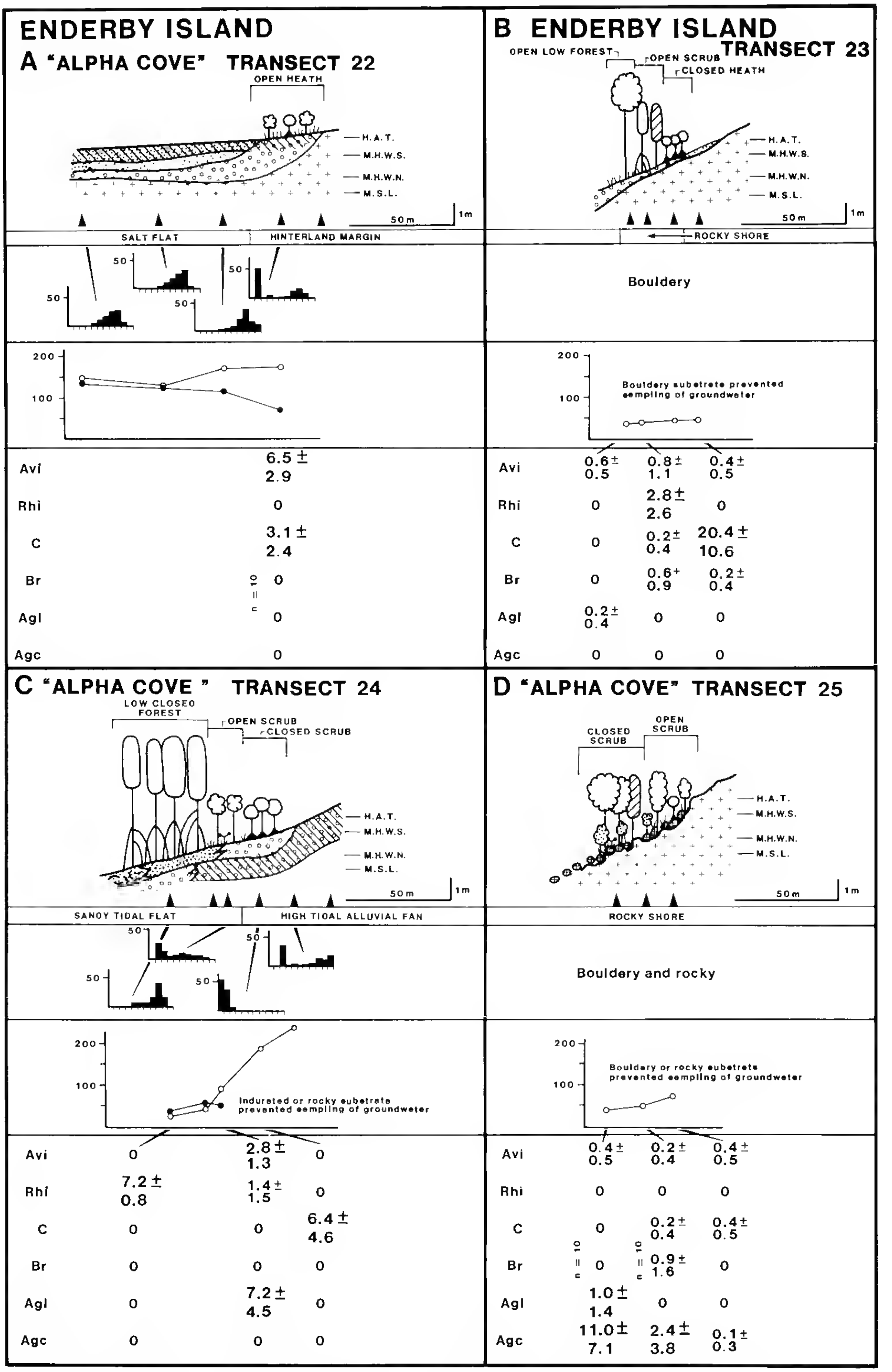
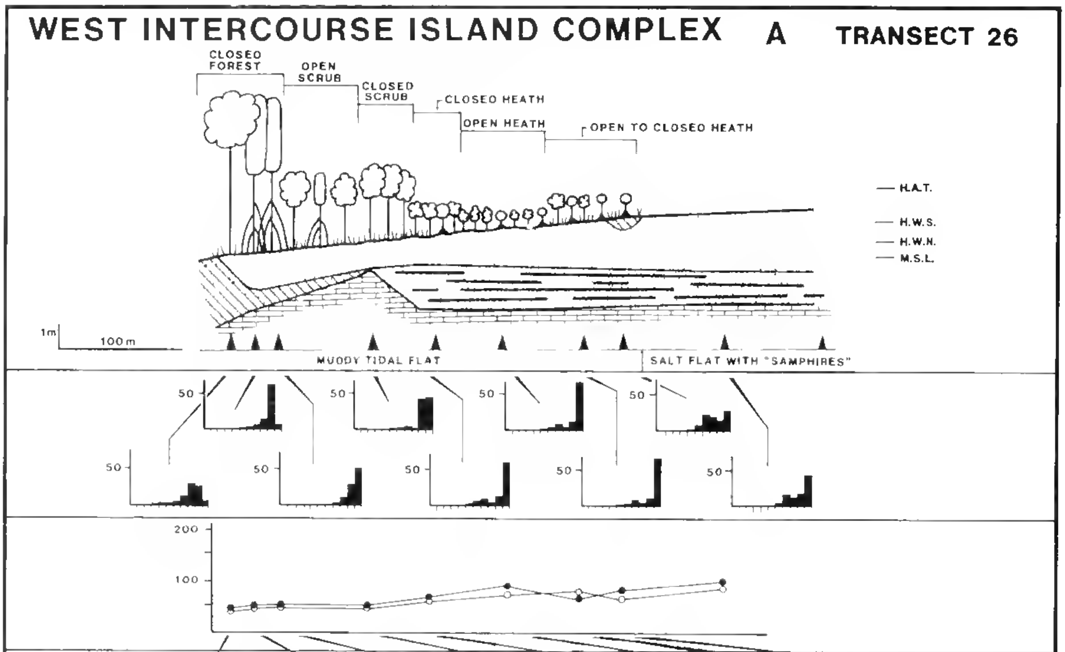
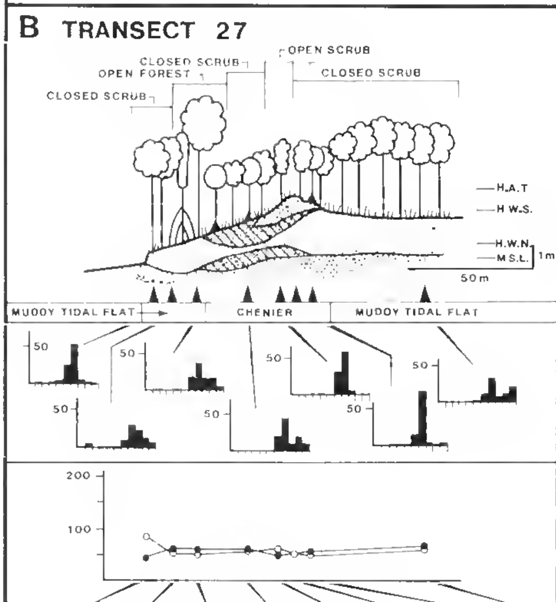


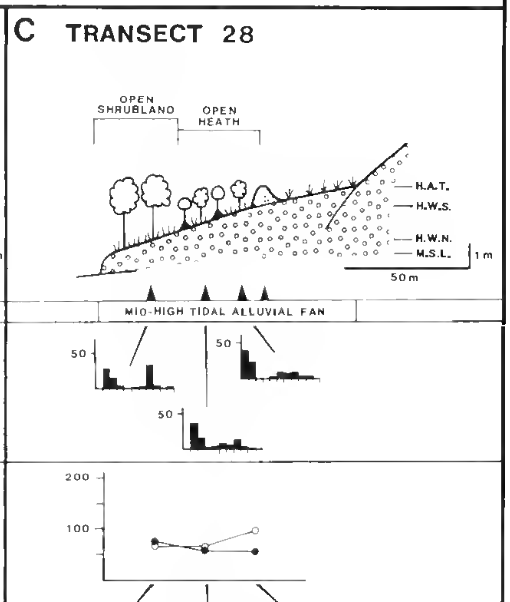
Figure 29.—Profiles showing the information obtained from field surveys. A, Transect 22, "Alpha Cove", Enderby Island. B, Transect 23, "Alpha Cover", Enderby Island. C, Transect 24, "Alpha Cove", Enderby Island. D, Transect 25, "Alpha Cove", Enderby Island.



Avi	1.3± 1.3	0.1± 0.2	4.0± 1.2	2.8± 1.5	15.2± 4.4	23.0± 4.8	11.0± 4.8	0
Rhi	0	3.3± 1.4	0.8± 0.8	0.4± 0.9	0	0	0	0
C	0	0	0	0.2± 0.4	1.0± 1.2	1.0± 1.2	7.4± 3.6	0.6± 0.5
Br	0	0	0	0	0	0	0	0
Agl	0	0	0	0	0	0	0	n = 10 0
Agc	0	0	0	0	0	0	0	0



Avi	2.6± 1.1	3.0± 1.6	1.4± 0.9	2.0± 0.7	1.0± 0.7	1.4± 1.1	1.8± 0.8	5.6± 3.1
Rhi	0	0.4± 0.5	0	0	0	0	0	0
C	0	0.2± 0.4	0.4± 0.5	18.6± 10.3	1.2± 1.3	0.2± 0.4	2.8± 2.3	0.2± 0.4
Br	0	0	0	0	0	0	0	0
Agl	0	0	0	0	0	0	0	0
Agc	0	0	0	0	0	0	0	0



Avi	3.2± 2.6	8.6± 3.8	4.3± 1.5
Rhi	0	0	0
C	0	4.8± 3.2	0
Br	0	0	0
Agl	0	0	0
Agc	0	0	0

Figure 30.—Profiles showing the information obtained from field surveys. A. Transect 26. West Intercourse Island Complex. B. Transect 27. West Intercourse Island Complex. C. Transect 28. West Intercourse Island Complex.

Description of selected areas

This section is a description of the coastal and mangrove environments of several areas which cover the variability of habitat type and coastal setting in the Dampier Archipelago. The areas chosen for description are (Fig. 2):

1. King Bay
2. Withnell Bay
3. Conzinc Bay
4. Searipple Passage
5. Angel Island/Gidley Island
6. Malus Islands
7. Lewis Islands
8. Enderby Island
9. West Intercourse Island area.

Each of these areas are described in a similar format of: (1) coastal setting, (2) large scale and medium scale geomorphology and mangrove habitats and (3) mangrove vegetation. This approach thus provides information on the mangrove and their environments within one of three categories: on the large important mangroves areas in the Dampier Archipelago (eg. King Bay and Western Intercourse Island area), on other typical areas (such as Lewis Islands) and on unique or atypical areas (such as Searipple Passage). Figure 32 schematically illustrates some of the key features occurring in selected areas. While the descriptions of the selected areas indicate a degree of similarity between various parts of the archipelago in that there is a recurrence of habitat types, they also highlight the heterogeneity that occurs at all scales and throughout the region. This aspect of heterogeneity thus emphasises the peculiarities of each selected area.

1. King Bay

Coastal setting: King Bay is an E-W oriented embayment system formed by tidal sedimentation and dune backfill of a narrow strait between two former islands. The embayment is backed by rocky hinterland to the north and south, and is backed by an extensive supratidal flat followed by dunes of Hearson Cove to the east. The main King Bay embayment thus forms a V-shaped embayment system. However, its north and south margins are markedly scalloped and indented such that a number of smaller subsidiary embayments are developed, some of which are tidal mud filled and some beach/dune backfilled.

Geomorphology and habitats: The King Bay embayment is a typical example of a large narrow embayment system (Fig. 12A). At the exposed entrance to the embayment there are local rocky and bouldery shores and dune-backed beaches. The southeast shore of King Bay is more exposed to wave action (from westerly, northwest, and refracted northerly sectors) so that it is dominated by spits and sandy tidal flats. Generally, the King Bay system is dominated by typical medium scale geomorphic units of embayment settings, namely muddy tidal flat, sandy tidal flats, spits, alluvial fans, hinterland margin, rocky shores and tidal creeks. In addition, at the mouths of tidal creeks there is local development of shoals.

Mangrove vegetation: Density, floristic diversity and width of the mangrove belt are well developed in King Bay. The vegetation types typical of the various medium scale geomorphic units/habitats in embayment settings are well represented in the area (Fig. 12B). At the medium scale *Avicennia* and *Rhizophora* forests and scrub are dominant (Fig. 12C). At the smaller scale, various other floristic and structural units are developed in response to small scale coastal heterogeneity. For instance: there are additional species and marked zonation around small and localised high-tidal alluvial fans where there is freshwater seepage; there is structural zonation and a greater diversity of species adjoining the sandy spits; and there is an assemblage of *Avicennia-Aegialitis-Aegiceras* on local shoals.

2. Withnell Bay

Coastal setting: Withnell Bay is a NE-SW oriented broad rectangular embayment some 2 km long and 0.8 km wide formed by marine flooding of a valley system eroded from a series of dyke rocks (Fig. 13A). For most of its margins the embayment is bordered by rocky shores, however sedimentary fill at the northeast extremity has developed tidal flats. In contrast to King Bay and Conzinc Bay, Withnell Bay has relatively straight margins with little development of smaller subsidiary embayments.

Geomorphology and habitats: Withnell Bay is an example of a large open embayment system where wave action has dominated the development of tidal flat features. There is little or no sediment along most of the shores such that rocky shores dominate. Where sediment has accumulated there is development of wave-dominated features, such as sandy tidal flats, spits and dune-backed beaches (Fig. 13B). Other important and well-developed mangrove habitat features are: a mid tidal alluvial fan; a high tidal alluvial fan; high tidal dune margin habitat; rocky channel or chasm (= a narrow embayment).

Mangrove vegetation: Mangroves occur as a relatively thin belt in Withnell Bay and are best developed on the sandy tidal flat, the mid-tidal alluvial fan, along spits, along the rocky channel/chasm to the southwest, and bordering the dune terrain. *Avicennia* scrub is dominant (Fig. 13C). Elsewhere mangroves are generally only developed in patches on rocky shores and pocket sandy beaches. Habitat heterogeneity occurs at the small scale and as a result there is marked local floristic and structural variability in mangrove assemblages. For example in the northeast corner of the bay, there are assemblages of spit fringe, hinterland fringe, high tidal alluvial fan, dune fringe and sandy tidal flat within an area 200 m x 200 m (Figs. 13B,C).

3. Conzinc Bay

Coastal Setting: Conzinc Bay is an open but elongate embayment, oriented SW-NE. It measures some 1 km across and is approximately 3 km long. It has formed by marine flooding and sedimentary backfill of a valley narrowing to the NE.

Geomorphology and habitats: Conzinc Bay contains three main categories of large scale geomorphic settings for mangroves; these are: straight coast of dune-backed beaches; straight coast of rocky bouldery shores; and an embayment. The beach shores occur along the southwest shore of the bay. They are open with steep slopes and are backed by dunes. Locally there is developed a high tidal lagoon system. Rocky shores occur dominantly along the northern headland and southwest shores of the bay. The embayment setting occurs in the extreme northeast of Conzinc Bay and there are developed spits, muddy tidal

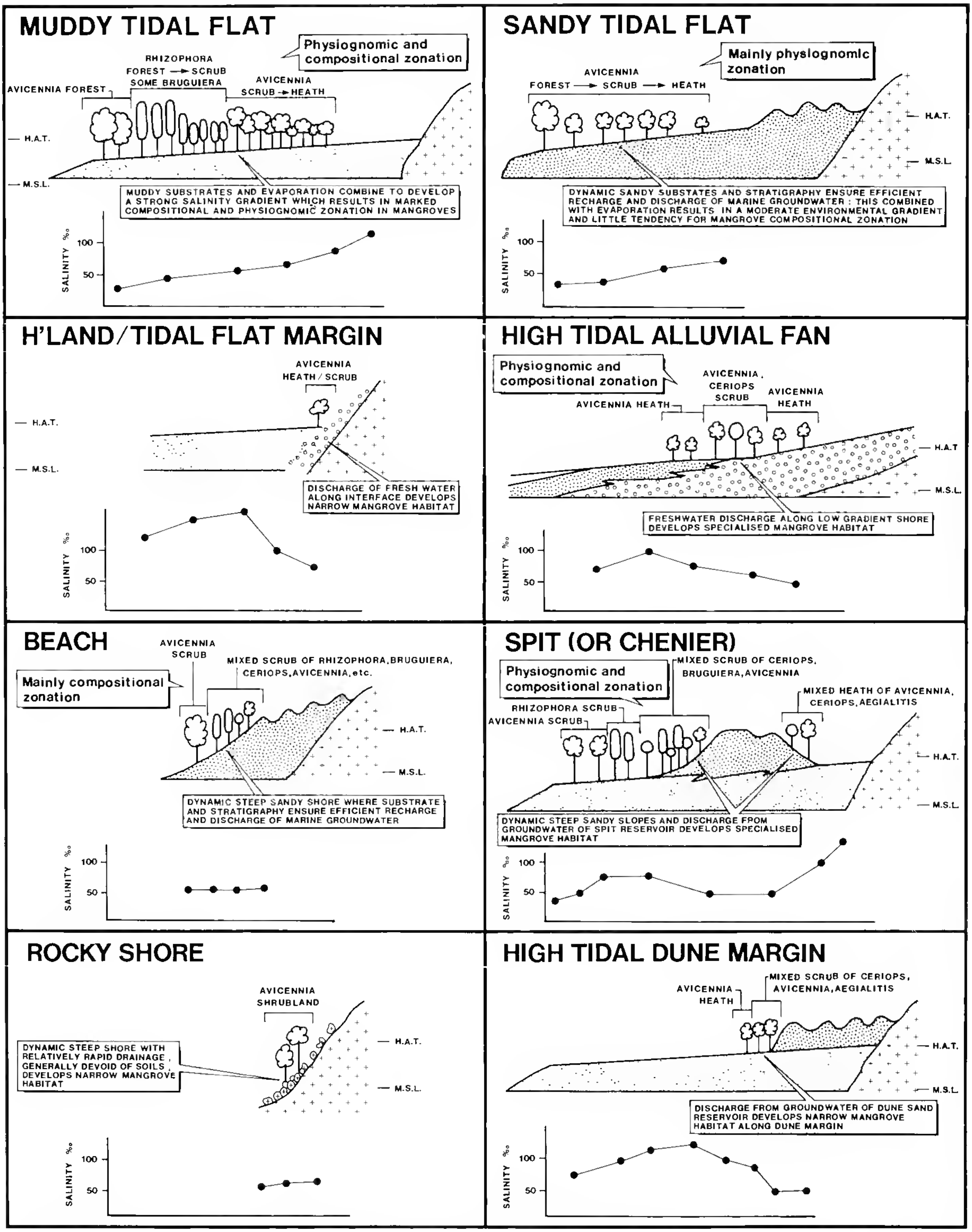


Figure 31.—Summary diagram showing key habitat features, such as slope, salinity gradients, substrates and physico-chemical processes, and the resulting mangrove composition, structure and physiognomy for the main assemblages in the Dampier Archipelago.

flat, sandy tidal flat, gravel tidal flat, high tidal alluvial fans and hinterland margin habitats. The southeast coast of the embayment is fairly exposed to refracted swell and also is exposed to westerly to southwesterly waves. A gravel tidal flat and mid tidal alluvial fan mark the junction between the more sheltered northern sector of the embayment and the exposed southern coast comprised of rocky shores and sandy beaches (Fig. 14A).

Mangrove vegetation: Mangrove vegetation is best developed in terms of width and biomass on the muddy tidal flat, where there is a zoned scrub of *Avicennia* and *Rhizophora*, and on the mid tidal alluvial fan, which supports *Avicennia* scrub (Fig. 14B, C). A *Bruguiera* scrub fringes the spit which occurs immediately behind the north shore headland. The other habitats support more spatially narrow or less dense mangrove stands such as *Avicennia* shrubland on the rocky shores and tracts of the gravelly tidal flat.

4. Searipple Passage

Coastal setting: Searipple Passage is a narrow strait, 6 km long and 1 km wide, separating Burrup "Island" from Dolphin Island. The strait has formed by erosion of E-W oriented fractures and dykes. Presently the strait is underlain by Pleistocene limestone overlying Precambrian bedrock. The limestone forms a pavement at *c.* LWN, and is undercut and eroding at its east and west extremeties to form wide deep-water channels. The north and south shores of Searipple Passage are markedly indented or scalloped such that small embayments several hundred metres long and less than 100 m across are developed. The strait tends to be dominated by waves translating only from east and west, and by turbid tidal currents from the adjoining Nickol Bay. Nonetheless the deeply indented shorelines are protected from these wave directions and consequently are accumulating mud.

Geomorphology and habitats: The large scale geomorphic components of Searipple Passage are: the passage itself; embayments dominating the north and south shores; small islands. Mangroves occur on the small islands and the embayments (Fig. 15A). Within the embayments there is sediment accumulation and hence there is the typical range of medium scale geomorphic and habitat units: rocky shore headlands, hinterland margin, high-tidal alluvial fans, muddy tidal flat and tidal creeks. Locally sand-filled embayments have dune-backed beach shores (Fig 15A,B). A few islands and reefs are scattered through the central Searipple Passage system. These may be developed merely to MSL as bedrock prominences and therefore not as mangrove habitats, or may be larger bedrock islands now flanked by extensive limestone (beachrock and Pleistocene limestone) and sediment deposits.

Mangrove vegetation: Well developed and zoned scrub of *Rhizophora* and *Avicennia* dominate the small, mud-filled embayments along the shores of the strait (Fig. 15C). *Bruguiera* shrubs also are a common component of the *Rhizophora* zone; this contrasts with areas elsewhere where the zone of *Rhizophora* tends to develop pure stands or tends to be associated with uncommon *Bruguiera*. *Avicennia* and *Rhizophora* mixed scrub occurs on the muddy accumulations developed peripheral to the large island in Searipple Passage. *Bruguiera* and *Ceriops* occur in association with the spit on this island. Rocky shores and dune-backed beach shores are vegetated by *Avicennia* scrub and shrubland.

5. Angel Island and Gidley Island

Coastal setting: The Angel Island/Gidley Island system is a series of elongate bedrock islands separated by channels formed from inundated valleys developed by eroded dyke rock and fracture systems. For most of the length of the coast in the island complex straight rocky shores dominate. The west shores of Angel and Gidley however are comprised of alternating headlands and embayments, but since these shores are exposed to wave action the embayments are back-filled with beach/dune sediments. The most sheltered shores occur along the channel or strait that separates Angel and Gidley Islands.

Geomorphology and habitats: Rocky shores and dune-backed beach shores dominate the Angel Island/Gidley Island system. In the more protected passage between the two islands, rocky and bouldery shores, fronted by a narrow strip of sandy tidal flats, are dominant, but there is locally developed a diversity of small habitat units of connective tidal-lands, limestone pavement, pockets of dune plain and small embayments with the units of rocky headland, sandy tidal flats, high tidal alluvial fan, and hinterland margin (Fig. 16A).

Mangrove vegetation: Scrub and shrubland, mainly of *Avicennia*, inhabit local areas along the extensive rocky shores and dune-backed beach shores of this system. Within the relatively protected strait there is more variability in the composition and structure of mangrove vegetation with the occurrence of *Ceriops*, *Rhizophora*, and *Bruguiera* (Fig. 16B, C) in association with the greater habitat diversity. Mixed *Avicennia* and *Rhizophora* scrub dominates the rocky shores with *Bruguiera* scrub and *Ceriops* scrub also locally present. These floristic combinations are uncommon for rocky shore assemblages in the Dampier Archipelago region. Mixed *Avicennia* and *Aegialitis* scrub also occur, and this combination is more typical of rocky shores in the region. The sandy tidal flats of the small embayments support zoned scrub of *Avicennia* and *Rhizophora*. There also is an unusual combination of *Bruguiera*, *Ceriops*, *Rhizophora* and *Avicennia* mixed scrub on the high tidal alluvial fan of this embayment.

6. Malus Islands

Coastal setting: The Malus Islands are a series of small bedrock islands connected by tidal and emergent sand spits. On the southern and relatively more protected side of the system there is local development of mangrove.

Geomorphology and habitats: The Malus Island system represents an example of a locally developed habitat where partial protection from prevailing waves has developed a relatively small area of sandy coast amenable to mangrove. The mangrove habitat is comprised of a steep sandy beach and adjoining bouldery shore.

Mangrove vegetation: Scrub of mixed *Avicennia*, *Rhizophora*, *Bruguiera*, *Ceriops* and *Aegialitis* occur in this local small development of mangrove.

7. Lewis Islands

Coastal setting: The Lewis Islands are composed of East Lewis Island and West Lewis Island. The terrain of the large, irregular, bedrock islands is well dissected and accordingly the coastal topography is dominated by rocky shores alternating with small scale embayments, back filled either by beach/dune sediment on exposed shores, or by tidal flat sediment in protected environments. The two islands are connected by tidal spits which are an extension of sandy cusps developed on the shores; these spits span the inter-island channel.

Geomorphology and habitats: Four coastal geomorphic settings are present on the islands: straight coasts of rocky or gravelly shores; straight coasts of sandy beaches; straight coasts of narrow sandy tidal flats; and embayments. Rocky and bouldery shores are the main type of coastline because of the exposed nature of the islands. Sandy beaches and sandy tidal flats, backed by dunes, are developed along some portions of the straight coast, along the cuspate segment of coast (Fig. 17), and within small exposed embayments. The embayment settings, although small and not common on these islands, exhibit the largest variability of habitat, with the development of tidal flat, hinterland margin, high-tidal alluvial fans and rocky headlands.

Mangrove vegetation: Mangroves along the rocky shore are dominated by *Avicennia* shrubland and scrub with less common subsidiary occurrences of mixed *Avicennia* and *Rhizophora* scrub. Those along dune-backed beach or sandy tidal flat shores are composed of *Avicennia* scrub and shrubland (Fig. 17). The vegetation formations on rocky shores and dune backed beach shores are the most common types along the Lewis Island system. In the localised embayment setting there is development of more diverse mangrove assemblages in response to development of diverse habitats, but *Avicennia* and *Rhizophora* scrub are most common.

8. Enderby Island

Coastal setting: Enderby Island is a markedly indented/scalloped island system which has formed by the post glacial transgression isolating a series of bedrock hills (Fig. 18). Earlier in the Holocene the island system was comprised of at least 5 separate, closely spaced islands. However, sedimentary fill by tidal mud deposits, sand spits and dunes has formed connective land bridges such that the main island today is a complex amalgamation of these once isolated smaller islands. This sedimentary modification and addition has also resulted in development of various shore types additional to the simple distribution of rocky shores.

Geomorphology and habitats: Enderby Island contains the three major categories of large scale geomorphic settings for mangroves. i.e.. embayments, straight coast of dune backed beach shores. and straight coast of rocky bouldery shores. The embayment settings range in size from small systems some 100 m across, to large systems some 1 000 m broad and may be muddy or sandy. They occur predominantly on the south to east facing sectors of the island, protected from prevailing swell. The south facing embayments also are protected from prevailing wind waves. The embayments have the typical range of medium scale geomorphic units and habitats. ie, muddy tidal flat, sandy tidal flat, spits, rocky shore, hinterland margin and high tidal alluvial fans. The dune-backed beach shores are widespread but discontinuous along Enderby Island. The best developed beach-dune shores occur on the north facing coasts that receive prevailing swell and refracted wind waves. Generally beach-dune shores are comprised of a steep beach with a backing dune. Locally there is developed the high tidal lagoon system wherein a tidal creek draining a dune terrain has been partly blocked by shoreline spits and dunes. The rocky/bouldery shores are widespread units. Generally, they are either fissured rock shores or bouldery shores with local small pocket beaches and sand sheets.

Vegetation and habitat maps of the 2 largest embayments on the island "Alpha Cove" and "Zeta Bay" are presented in Figs. 19 and 20.

"Alpha Cove" is a broad embayment, opening to the north east and is consequently exposed to wind waves. As a result the inner portion of the cove consists of a sandy tidal flat. Rocky shore habitats extend into the mouth of the cove, and tracts of tidal flats are flanked at their landward edge by sand accumulations.

"Zeta Bay" has been formed by dune backfill of an inter-island strait. Interestingly, this dune/tidal flat contact is marked by freshwater seepage and a fringe of mangrove has established. This bay has developed in the lower energy conditions behind the rocky shores and a sand spit constriction at its narrow mouth, and consequently consists predominantly of a muddy tidal flat.

Mangrove vegetation: Mangrove vegetation is limited in extent along the shores of Enderby Island and occurs mainly in the two large embayments, the most extensive occurring in "Zeta Bay". In these embayments the mangroves form forests, scrub and heath typical of embayment habitats.

The rocky and gravelly shore assemblages of "Alpha Cove" are exceptionally well developed and regionally unusual, consisting of dense stands of floristically mixed scrub. *Avicennia* scrub dominates the main mangrove belt, although zones of both *Rhizophora* scrub and forest occur. *Ceriops* scrub occurs on sandy beaches. The narrowness of the tidal flat along much of the shores of this cove has meant that salt flat generally is not widespread, although some patches of heath and shrubland grading into incipient salt flat occur in the middle of the zones of *Avicennia* scrub.

Zoned *Avicennia* and *Rhizophora* scrub dominate the main mangrove flat of "Zeta Bay". *Avicennia* scrub and shrubland comprises the high tidal dune margin, high tidal alluvial fan, spit margin and limestone pavement assemblages. *Bruguiera* was noted to occur in scrub with *Rhizophora* and *Avicennia* as a spit fringe assemblage at the mouth of the embayment. Overall, however, the mangroves of this embayment are not structurally or floristically diverse.

Elsewhere on Enderby Island mangrove cover along exposed rocky and bouldery shores and dune-backed beach shores is discontinuous, patchy and narrow.

9. West Intercourse Island Area

Coastal setting: The area south of West Intercourse Island has developed by marine flooding and sedimentary fill of low-lands between a series of bedrock hills (now islands). This area adjoins the Maitland Delta complex to the west and the alluvium/sand plains of the mainland hinterland to the south. The West Intercourse Island area is significantly protected from wave action,

and consequently large areas of connective tidal-lands have developed. The area is however subject to tidal current flow through the abundant channels in the system.

The best developed large scale geomorphic units in the area are the connective tidal-lands. These units are composed of mud and sand accumulations forming tidal flat surfaces transversed by tidal drainage channels and creeks. The connective tidal-lands bridge the alluvial sand plain of the mainland hinterland to Burrup "Island" and West Intercourse Island, and also bridge a series of smaller islands that are amalgamated into an island complex that comprises the West Intercourse Island system.

Geomorphology and habitats: The West Intercourse Island area is a complex coastal system comprised of: rocky and gravelly shores; connective tidal-lands; and major tidal creeks and straits. Rocky shores occur along the channel defined by the south shore of West Intercourse Island and the north shore of the southwest part of Burrup "Island". These shores are comprised of alternating stretches of fissured rock shores, bouldery to gravelly shores, local bedrock prominences (islets), pocket beaches, discrete alluvial fans and locally developed small embayments which are small scale sediment pockets (Fig. 21).

Within the connective tidal-lands system there are muddy tidal flats, spits and cheniers, tidal creeks, shoals, rocky shores, and, where there is nearby bedrock, hinterland margin units and high-tidal alluvial fans. The junction of this tidal flat terrain with the sandy mainland hinterland is a system of low red sand hummocks dissected by small creeks around their margins.

Mangrove vegetation: Mangroves are best developed, in terms of abundance and diversity, on the connective tidal-lands. These systems are dominated by muddy tidal flats which support a zoned assemblage of *Avicennia* forest, *Rhizophora* scrub, *Avicennia* scrub and locally *Ceriops-Avicennia* heath, grading to landward into a salt flat.

Ceriops-Avicennia scrub and shrubland occur along the margins of spits and cheniers in the area (Fig. 22). Tidal creek banks support *Rhizophora-Avicennia* low forest or scrub and, on accretionary points, *Aegiceras-Aegialitis* heath. Mid-channel shoals within creeks, depending on geomorphic stage of development, support heaths of *Aegiceras-Aegialitis*, as well as scrub and low forest of *Rhizophora* and *Avicennia*. Where locally developed, hinterland margins and high-tidal alluvial fans support *Avicennia* heath with subordinant *Ceriops*.

The rocky shore mangrove formations consist of a narrow scrub (up to 10 m wide) dominated by *Avicennia* with subordinate *Rhizophora*. The local areas where alluvium has penetrated onto the shore to develop high-tidal to mid-tidal alluvial fans support a well developed, zoned mangrove assemblage where *Avicennia, Rhizophora, Ceriops*, and *Aegialitis* contribute to heath, scrub and low forests (Fig. 22).

Discussion

The various areas described above provide several insights into mangroves and their habitats in the Dampier Archipelago. Firstly, it is obvious that mangrove formations inhabit a wide range of small scale habitats that are developed by regional processes and small scale processes interacting with the local environment. Thus a terrain comprised of dissected bedrock will develop, depending on aspect and coastal processes, a range of habitats such as mud-filled embayments, sand-filled embayments, spit-lined headlands, bouldery or rocky headlands, high-tidal alluvial fans, tidal creeks, etc. Because of the heterogeneity in landform and its relationship to meterologic and oceanographic aspect (waves and wind), there is a concommitant heterogeneous distribution of mangrove habitat.

The embayment setting provides the most internally heterogeneous aggregate of habitats in the Dampier Archipelago. The heterogeneity is a function of ancestral landform interacting with waves and wind. Superimposed on this is the further pattern of discordant incursions of alluvial fans shed onto the tidal zone by upland streams. The interaction of marine water and fresh water along localised, or specific, or ubiquitous aquifers also provides small scale habitat heterogeneities. As a result, it may be considered that mangroves have opportunistically inhabited the variable habitats, resulting in the complex mosaic of assemblages and populations evident today.

However, while small scale heterogeneity is emphasised here it should be noted that many of the habitats are recurring. For instance, rocky shores, with or without continuous mangrove cover, are essentially widespread units and may be considered to be *the* most common mangrove habitat (per unit length of coast). Other units such as spits, or alluvial fans, while discrete in occurrence and limited in area, also are quite widespread as units. They occur virtually in every setting and in most of the described areas.

Secondly, the best developed mangrove formations, as reflected in *luxuriance, abundance*, and *diversity*, occur in embayment settings and connective tidal-land settings, where there is an accumulation of tidal mud. Here the habitats are protected from wave action and the substrates support a rich benthic fauna. The areas of West Intercourse Island and King Bay exemplify this.

Thirdly, the zonation involving the greatest number of species occurs in 2 main settings: (1) peripheral to those alluvial fans that intrude onto the tidal flat across the full mangrove tidal range; and (2) peripheral to a sand terrain such as spits and beaches. In both cases the substrates are coarse, well drained and are subject to fresh water seepage or at least oceanic water seepage.

Finally, since there is only a *small species pool* in the region, the environmental forcing factors can only influence three aspects of mangrove population; these are:

(1) composition of populations, by regulating and eliminating species,
(2) structure, and
(3) maintenance of population.

Environmental gradients and differences between habitats therefore are reflected in a variety of structural/physiognomic categories within a limited floristic assemblage. Thus *Avicennia* will form forests of

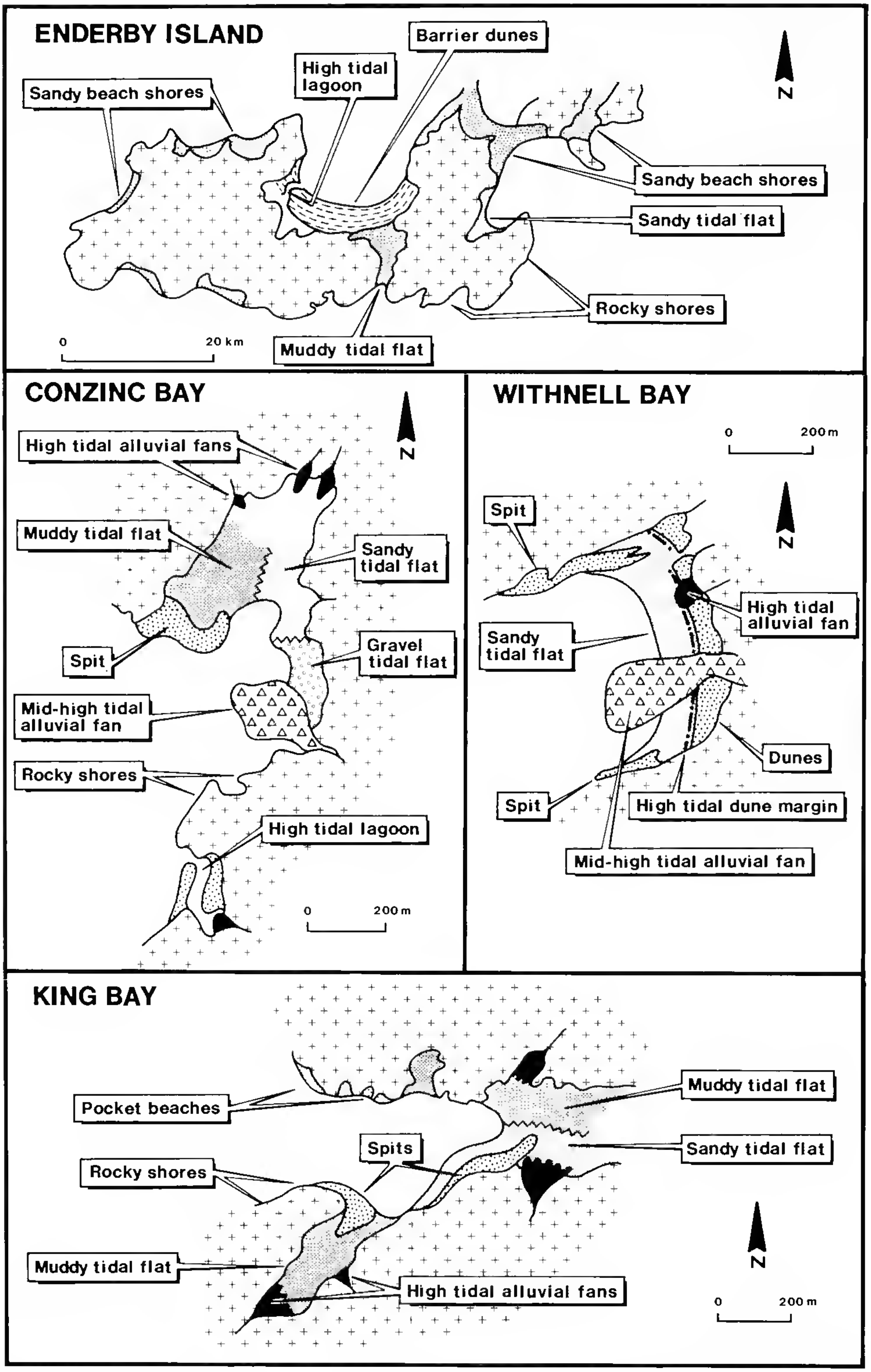


Figure 32.—Summary diagram showing main features or unique features of the various selected areas in Dampier Archipelago. At this scale the heterogeneity of the coast is evident but the recurrence of some specific geomorphic units, such as alluvial fans and spits, is also evident.

recumbent mature and overmature trees in one habitat, it will develop scrub of multi-stemmed shrubs in another, and perhaps it will form a heath of columnar shrubs in a third. This aspect of differential response of mangrove composition, physiognomy, structure and maintenance to variable habitats has to be addressed and understood if environmentally meaningful classifications of floristics and structure are to be developed for mangrove vegetation.

The approach adopted in this study has emphasised the physico-chemical factors that lead to habitat variability and coastal heterogeneity at various scales of reference. Mangroves then are viewed simply as opportunistic inhabitants of this variably developed coast.

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